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Volume I. Description of Data

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Volume I documents the meteorological and sulfur dioxide data collected during three test periods of the New York City Air Pollution Project of 1964-1969. A detailed description of all the data is presented in Volume I. Volume II supplements Volume I and contains: (1) emission rates of sulfur dioxide, heat, and moisture; (2) sulfur dioxide concentrations measured from fixed sites and from automotive platforms; and (3) vertical profiles of sulfur dioxide concentrations and temperature made from helicopters. Other data collected during the Project are available on microfilm: (1) hourly synoptic maps showing "surface" windspeed and direction at 97 sites and showing streamline and isotach analyses; and (2) 132 bihourly maps of hourly average sulfur dioxide concentration isopleths for the 11 days of the three "primary" test periods. Pibal measurements of winds aloft (578) balloon launches) are available on magnetic tape. The purpose of documenting and publishing all these data (in Volume I, Volume II, microfilm, and magnetic tape) is to make these valuable data readily available for further research and applications.

Volume II, the microfilm, and the magnetic tape (with card deck and print-out for reading the tape) are available from the National Technical Information Service in Springfield, Virginia.

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by

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The helicopter soundings of the Project were carried out by Betsy and Sandy Proudfit of the Sign-X Corporation of Essex, Connecticut. Additional information concerning the analysis of the helicopter soundings was supplied by Dr. Paul Halpern of the IBM Scientific Center in Palo Alto, California.

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DEDICATION

This report is dedicated to the memory of Dr. Ben Davidson of the Department of Meteorology and Oceanography at New York University. Dr. Davidson was the principal investigator of the New York City Air Pollution Project conducted by New York University.

SECTION I

INTRODUCTION

BACKGROUND

From 1964 to 1969, New York University (NYU) conducted the New York City Air Pollution Project under the sponsorship of U.S. Public Health Service Grant No. AP-00328-04. The late Dr. Ben Davidson of the Department of Meteorology and Oceanography, New York University, directed the Project. The main goal of the Project, as described by Davidson (1967), was to develop an urban air pollution model for predicting the distribution of sulfur dioxide (SO_2) in New York City (NYC). For details of the final model, see Shieh (1969) and Shieh, Davidson, and Friend (1969). In addition, various members of the Project used the data collected by the extensive monitoring networks established during the Project. The value of these data is attested to by the large number of titles preceded by asterisks in the list of references at the end of Volume I. The asterisks designate research carried out using data collected during the Project.

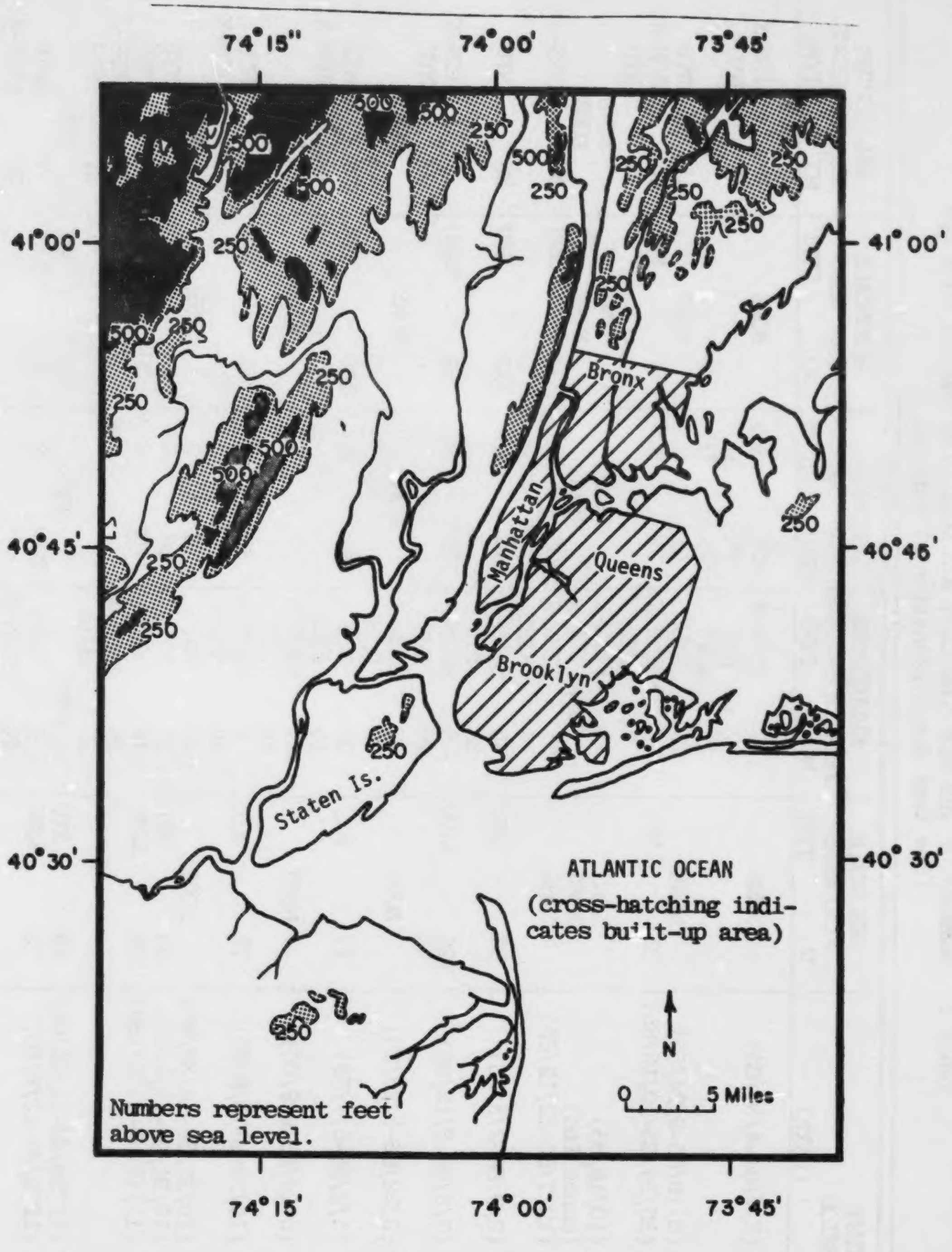
The data collected in the New York City Air Pollution Project were, however, never published due to the untimely death of Dr. Davidson. In 1974, the Environmental Protection Agency awarded a contract to San Jose State University (SJSU) to organize, collate, and publish the data. Meteorologists believed that the data set was unique and that it would be extremely useful to investigators interested in studying the dynamics of the urban boundary layer and/or the distribution of pollutants within the atmosphere over NYC. The contract group at San Jose State University prepared the following to document the previously unpublished New York City Air Pollution Project data: (1) Volume I, which describes all the data in detail; (2) Volume II, which presents (a) emission rates of sulfur dioxide, heat, and moisture, (b) sulfur dioxide concentrations measured from fixed sites and from automotive platforms, and (c) vertical profiles of sulfur dioxide concentrations and temperature made from helicopters; (3) microfilm, which contains (a) hourly synoptic maps showing "surface" windspeed and direction at 97 sites and showing streamline and isotach analyses, and (b) 132 bihourly maps of hourly average sulfur dioxide concentration isopleths for the 11 days of the three "primary" test periods; and (4) magnetic tape, which contains pibal measurements of winds aloft (578 balloon launches). Volume II, the microfilm, and the magnetic tape (with card deck and print-out for reading the tape) are available from the National Technical Information Service (NTIS) in Springfield, Virginia.

PROJECT DESCRIPTION

As shown in Figure 1, the area studied in the Project is about 30% water, 60% open country, and 10% built-up urban or suburban land. Most of the area is close to sea level, but the northwestern 10% of the area is highlands ranging in elevations up to 165 m above mean sea level.

A summary of the most important data collected during the Project is given in Table 1. As can be seen from the table, the Project included 12 test periods (T-1 to T-12), of from 3 to 5 days duration, during the period from September 1965 to December 1966. In addition, preliminary data (PT-1) were obtained from July 1964 to April 1965, and additional data were obtained on days intermediate between several of the test periods (I-2/3 to I-8/9).

One of the 12 test periods (T-3) was cancelled before any data were collected, and over the years some data have been lost from T-1, T-4, and T-11. Of the remaining eight tests, three (T-6, T-10, and T-12) were selected for complete documentation because of their interesting meteorological conditions, observed SO_2 concentration patterns, general overall quality of data and previous analysis by the Gaussian puff model of Shieh (1969). Synoptic conditions for each of the 12 test periods are given in Appendix I. Greater detail is supplied for the three "primary" test periods selected for complete documentation.


74°15''
74°00'
73°45'
41°00'
40°45'
40°30'
500
250
Bronx
Manhattan
Queens
Brooklyn
Staten Is.
ATLANTIC OCEAN
N
0 5 Miles
74°15'
74°00'
73°45'

(cross-hatching indicates built-up area)

Numbers represent feet above sea level.

Figure 1. Topography of study area.

TABLE 1. SUMMARY OF THE NEW YORK CITY AIR POLLUTION PROJECT DATA SET
(See text for explanation of entries.)

TEST PERIOD CODE	(DATE)	MESOSCALE WIND MAPS NO.	TYPE	HELICOPTER TEMP. SOUNDINGS NO.	TYPE	PIBAL WIND OBS. NO.	TYPE	MESOSCALE SO_2 MAPS NO.	TYPE	HELICOPTER SO_2 SOUNDINGS NO.	TYPE
PT-1	(7/7/64-4/30/65)	NONE		150	SIGN-X	853	S	NONE		49	SIGN-X
				7	NYU	74	D			7	NYU
				23	SJ25	136	DD				
T-1	(9/19/65-9/24/65)	NONE		15	NYU	43	S	NONE		15	NYU
T-2	(10/14/65-10/16/65)	36	NYU	53	SIGN-X	63	S	61	NYU	45	SIGN-X
				3	NYU					25	NYU
I-2/3	(10/18/65)	NONE		3	SIGN-X	NONE		NONE		NONE	
T-3	(cancelled)	NONE		NONE		NONE		NONE		NONE	
T-4	(12/7/65-12/12/65)	NONE		61	SIGN-X	126	S	61	NYU	36	SIGN-X
				15	SJ25						
T-5	(2/2/66-2/5/66)	96	NYU	33	SIGN-X	116	S	113	NYU	38	NYU
				38	NYU						
*T-6	(3/8/66-3/12/66)	120	SJSU	5	SIGN-X	202	S	60	SJSU	5	SIGN-X
				98	NYU					98	NYU
I-6/7	(3/22/66-3/23/66)	NONE		7	SIGN-X	NONE		NONE		NONE	
				2	SJ25						
T-7	(5/2/66-5/7/66)	72	NYU	59	NYU	240	S	106	NYU	59	NYU
				15	SJ25					49	SIGN-X
I-7/8	(5/24/66-9/9/66)	NONE		134	SIGN-X	2	S	NONE		NONE	
				29	SJ25						
T-8	(10/3/66-10/6/66)	72	NYU	5	SIGN-X	83	S	62	NYU	46	NYU
				46	NYU					5	SIGN-X
I-8/9	(10/25/66-10/27/66)	NONE		17	SJ25	18	S	NONE		NONE	
T-9	(10/31/66-11/1/66)	24	NYU	17	NYU	86	S	36	NYU	17	NYU
*T-10	(11/15/66-11/17/66)	108	SJSU	19	NYU	170	S	50	SJSU	19	NYU
				16	SIGN-X					16	SIGN-X
				37	SJ10					37	SJ10
T-11	(11/23/66-11/25/66)	48	NYU	NONE		NONE		72	NYU	NONE	
*T-12	(12/5/66-12/8/66)	72	SJSU	1	SJ10	209	S	36	SJSU	7	SJ10
				42	SIGN-X					33	SIGN-X

* Primary Test Period

LIST OF ARCHIVED DATA

This section summarizes the availability of the data collected during the New York City Air Pollution Project, referred to hereafter in the text as the NYU/NYC data set. Parts of the NYU/NYC data set are listed in Table 1.

It is hoped that the NYU/NYC data set will be of use to investigators wishing to model the various aspects of the urban boundary layer over NYC. Additional information or data can be obtained from Robert Bornstein of the Department of Meteorology at San Jose State University.

Emission Inventory

Most of the 1965 fuel usage data from which the SO_2, heat, and moisture emissions inventory was constructed at NYU is currently at SJSU, but some of them were lost while the data set was in storage. One of the 12 books containing the area source fuel usage data in a large area of Brooklyn is missing, as is the fuel usage data for some of the point sources.

The tabulated annual SO_2 emissions from all of the area and point sources, which were computed at NYU after the fuel usage data set was completed, are described in Section 2 of Volume I and are listed in Volume II. Section 2 of Volume I also contains a summary of the method by which the SO_2 emissions were used to estimate the annual heat and moisture emissions associated with the combustion of fossil fuels in NYC. Volume I also includes a summary of the method used to determine the daily and hourly emission rates of SO_2, heat, and moisture from the area and point sources.

Surface Wind Data

The original surface wind data rolls are generally not available, except for those from several of the sites operated by NYU. The available data rolls are currently at SJSU, as are the tabulated hourly averaged windspeed and direction data for many of the stations.

As indicated in Table 1, the bihourly surface streamflow and isotach analyses described in Section 4 of Volume I are available at SJSU for six of the test periods (indicated by "NYU"). In addition, hourly charts are available for three additional periods, i.e., those designated as the "primary" test periods (indicated by "SJSU"). These latter charts are available at SJSU and are on a microfilm that can be obtained from NTIS.

Pibal Wind Data

The original data sheets from all of the pibal launches listed in Table 1 are at SJSU. The data set, described in Section 5 of Volume I, includes single pibal launches (designated as "S"), double pibal launches (designated as "D"), and double-double pibal runs (designated as "DD").

Computer programs required to correct errors in the input data and to compute wind velocities are available at SJSU, and all of the corrected observations are on a computer tape at SJSU. The computed velocities from the three primary test periods are also on computer tape at NTIS, along with the computer program (deck and listing) required to read the winds from the tape.

Helicopter Soundings

The original helicopter strip charts containing the SO_2 and temperature soundings taken during the periods shown in Table 1 and described in Section 3 of Volume I are at SJSU. In addition, some of the strip charts obtained before the first test period contain additional soundings of wet-bulb temperature. All of the soundings, and some horizontal traverses, have been plotted, but only those from the three primary test periods are included in Volume II.

Surface SO_2 Observations

The original strip charts from the surface SO_2 observation network described in Section 6 of Volume I are available at SJSU. Bihourly analyzed surface charts are also available at SJSU for the 10 test periods indicated in

Table 1. The analyzed charts from three of the 10 test periods (i.e., the three "primary" test periods) are also on the microfilm at NTIS that contains the surface wind analyses. Finally, the tabulated hourly SO_2 values from all of the fixed surface sites, and plotted SO_2 values obtained during a series of automobile traverses across Manhattan taken during the sixth test period, are contained in Volume II.

SECTION 2

SOURCE EMISSION INVENTORIES FOR SO_2, HEAT, AND WATER

INTRODUCTION

During the New York City Air Pollution Project, Ingram, Kaiser, and Simon (1965) compiled, but did not publish, an inventory of the annual emission rates of SO_2 from the known fixed and mobile area and point sources in the New York Metropolitan region. Emissions were computed from fuel usage data obtained from the following sources: (1) the U. S. Bureau of Mines, which publishes an annual report on the shipment of fuel oil; (2) the New York Oil Heating Association; (3) the American Petroleum Institute; (4) the NYC Council Committee on Air Pollution; (5) the NYC Housing Authority; (6) the NYC Air Pollution Control Agency; (7) the NYC Fire Department; (8) the NYC Licensing Agency, which controls the installation, registration, licensing, and insurance of each furnace or power plant in NYC; and (9) the answers supplied to questionnaires.

The SO_2 emission data were used by Leahey (1969) and Leahey and Friend (1971) to compute the spatial distribution of the annual production of anthropogenic heat in New York due to fossil fuel usage. Their results were used in a model of the energy balance of the NYC area.

Volume II presents the 1965 area source emission inventory of SO_2, heat, and moisture produced from the combustion of fossil fuels in the NYC area. Similar annual emission rates are presented for the 378 point sources of SO_2 known to exist in the NYC area in 1965. The 1965 emission rates are used, even though the primary test periods selected for complete analysis were run in 1966. In addition, stack height and heat emission data are presented for many of the point sources so that estimates of plume rise values can be made. Finally, methods are presented to compute the daily and hourly emission rates of both the point and area sources.

ANNUAL SO_2 EMISSION RATES

The seven main types of fuel consumed in the NYC area, the uses to which they are put, and the annual rates of consumption of each in NYC in 1965 are listed in Table 2. Details on the composition of natural gas are given in Table 3. A breakdown of the fuel usage in each of the five boroughs of NYC is given in Table 4.

Because fossil fuels are composed of carbon, hydrogen, and sulfur, the combustion of these fuels produces oxides of sulfur, oxides of nitrogen, carbon monoxide, carbon dioxide, aldehydes, hydrocarbons, particulates, and water vapor. The quantities of these products put into the atmosphere depend on the rate of the combustion process, the content of impurities per unit mass, the equipment used for the combustion process, and the kinds of control devices installed on the equipment. For example, in the steam boilers of Consolidated Edison power plants, 1.4 lb of steam are added per 100 lb of residual oil consumed. This is done to atomize the oil, therefore increasing the efficiency of the combustion process. As a result, the water vapor emission rate from these stacks is greater than that from other point sources.

Sulfur is found in fuels in three basic forms: (1) pyritic sulfur, in the form of pyrite or marcasite; (2) organic substance; and (3) sulfate, in the form of iron or calcium sulfate. No evidence indicates that sulfur occurs initially in its free state. During combustion, about 70 to 90% of the sulfur appears in the combustion products as SO_2. About half of the sulfur in coal is carbonized in "byproduct ovens" and is retained as coke.

The basic equations for the combustion of coal (after the sulfur has been released) are:

TABLE 2. FUEL TYPES USED IN NYC DURING 1965

Fuel Type	Uses	Annual Consumption
Bituminous coal	Space heating and firing of industrial boilers	5.4×10^6 tons
Anthracite coal	Residential space heating	0.72×10^6 tons
Distillate oil #4	Space heating of small apartment houses	1.5×10^9 gal.
Residual oil #6	Space heating of large apartment houses and operation of industrial plants and factories	2.6×10^9 gal.
Natural gas	Fuel in power plants, energy for industrial plants, space heating, and home cooking	1.67×10^{11} ft.^{3}
Gasoline	Automobiles, trucks, and buses	1.1×10^9 gal.
Diesel	Automobiles, trucks, and buses	66.6×10^6 gal.

TABLE 3. COMPOSITION OF UNCOMBUSTED NATURAL GAS AND GENERATION OF WATER BY COMBUSTION

		After Combustion	
Paraffin Hydrocarbon	Fraction of Total Mass (%)	Water Content by volume (%)	Water Content by mass (%)
CH_4	93.45	186.90	210.26
C_2H_6	3.67	11.01	6.61
C_3H_8	1.78	7.12	2.92
C_4H_{10}	0.65	3.25	1.01
Others	0.45	--	--
	Total 100.00%	Total 208.28%	Total 220.8%

TABLE 4. FUEL USAGE BY AREA SOURCES IN NEW YORK CITY DURING 1965

FUEL TYPES	BRONX	BROOKLYN	STATEN ISLAND	MANHATTAN	QUEENS
DOMESTIC FUEL					
Bituminous coal (ton)	6343	3847	365	9221	2170
Anthracite coal (ton)	120507	148300	6554	175422	37556
Distillate oil (10^3gal)	132056	482305	28525	18288	412912
Residual oil (10^3gal)	215629	233111	14738	398552	120018
Natural gas (10^6 ft^3)	7520	29535	4922	4823	21367
COMMERCIAL-GOVERNMENT					
Bituminous coal (ton)	10000	6300	1000	10000	3000
Anthracite coal (ton)	41508	67202	30248	64313	31525
Distillate oil (10^3gal)	51501	152701	15417	32823	112734
Residual oil (10^3gal)	64170	179762	7240	85184	117980
Natural gas (10^6 ft^3)	2581	6341	1057	7298	5306
INDUSTRIAL FUEL					
Bituminous coal (ton)	20000	21037	1000	20000	15000
Anthracite coal (ton)	-	-	-	-	-
Distillate oil (10^3gal)	6427	25246	6185	9597	13341
Residual oil (10^3gal)	17425	116713	13372	33376	83057
Natural gas (10^6 ft^3)	1230	3040	506	3346	2515
POWER PLANTS					
Bituminous coal (ton)	-	432200	669700	2232900	1916600
Residual oil (10^3gal)	122438	253512	3948	185052	320630
Natural gas (10^6 ft^3)	9546	793	-	24779	30124
TRAFFIC					
Gasoline (10^3gal)	145586	233836	32006	253167	424113
Diesel (10^3gal)	8908	13692	2558	13529	27872
TOTAL FUEL USE					
Bituminous coal (ton)	36343	463384	672065	2272121	1936770
Anthracite coal (ton)	162015	215502	36802	239735	69081
Distillate oil (10^3gal)	189984	660252	50127	60708	538987
Residual oil (10^3gal)	419662	783098	39298	702164	641685
Natural gas (10^6 ft^3)	21147	39709	6485	40246	59312

$$C + O_2 \rightarrow CO_2 \qquad (1)$$

$$2C + O_2 \rightarrow 2CO \qquad (2)$$

$$2H_2 + O_2 \rightarrow 2H_2O \qquad (3)$$

$$S + O_2 \rightarrow SO_2 \quad . \qquad (4)$$

Equation 1 is the result of total combustion, while Equation 2 results during partial combustion.

The general formula for the combustion of oil and gas is

$$C_xH_y + (x + \frac{y}{4})\ O_2 \rightarrow x\ CO_2 + \frac{y}{2}\ H_2O, \qquad (5)$$

where

$$y = 2X + 2 \qquad (6)$$

if the hydrocarbon C_xH_y is saturated.

The sulfur content of each of the fuel types used in the NYC area is given in Table 5, as is the rate of emission of SO_2 per unit of fuel consumed.

Multiplication of the seven SO_2 emission factors of Table 5 by the corresponding seven fuel usage rates for each 1-mile by 1-mile grid area yields the SO_2 emission rates for each fuel type. Summation of these partial emission rates in each square grid area yields the annual SO_2 area (fixed and mobile) source emission rates tabulated in Volume II. The origin of the grid shown in Volume II is at Battery Park, which lies at the southern tip of Manhattan Island.

For studies requiring a more detailed emission pattern, a 0.5-mile by 0.5-mile area source grid was constructed over Manhattan Island, the region of maximum SO_2 emission. In computing the emission rates for this finer grid

TABLE 5. SULFUR CONTENT OF FUELS USED IN NYC

Fuel Type	Sulfur Content (%)	SO_2 Emission Factor
Bituminous coal	1.875	75.0 lb/ton
Anthracite coal	0.625	25.0 lb/ton
Distillate oil	0.575	85.0 lb/10^3 gal
Residual oil	2.450	390.0 lb/10^3 gal
Natural gas	4 ppm	0.6 lb/10^6 ft^3
Gasoline	0.030	5.0 lb/10^3 gal
Diesel	0.300	45.0 lb/10^3 gal

(see Volume II for results), emissions from the larger grid areas were assumed to be homogeneously distributed over built-up areas of the city, while emissions from the rivers around Manhattan and from Central Park were taken to be zero. Results presented in Section 6 demonstrate the effect of area source grid size on the concentrations of SO_2 predicted by an urban air pollution model.

A summary of the area source emissions of SO_2 in each borough, for each use of each fuel type is given in Table 6. Table 7 presents a tabulation of some of the same data by percentages. The total area source emissions of SO_2 in NYC during 1965 was 7.35×10^5 tons; Tables 8 and 9 summarize the breakdown of this emission by fuel type and source type, respectively.

There were 378 point sources of SO_2 in the NYC area in 1965, each with an annual emission rate of at least 100 tons of SO_2. The location of each point source is given both in Table 10 and in Figures 2(a), 2(b), and 2(c). Three projections are needed to show the many point sources. Only one set of latitude and longitude values is indicated for those sites having more than one stack, but separate stack parameters are given for each stack. As seen in the figure, the sources have been grouped according to source type; i.e., "P" is for power plants, "M" is for manufacturing concerns, "C" is for commercial concerns, and "H" is for hospitals. They are so listed with their annual SO_2 emission rates in Volume II. The 205 point sources within NYC emitted 3.67×10^5 tons of SO_2 per year, which is about one-half that emitted by the area sources within the city.

Stack height and diameter, as well as effluent temperature and velocity (needed for plume rise computations) are given for each stack, when available, in Table 10. The NYC Department of Air Resources supplied these stack parameters to SJSU from their 1970 emissions inventory. In many plume rise formulations, these stack parameters must be used to compute the effective flow rate at standard conditions, i.e., at an effluent temperature of $294^{\circ}K$. When stack parameters are not available for a given stack, it is recommended that the stack heat emission rates of Volume II be substituted. The stack heat emission values were obtained following the procedure outlined in this

TABLE 6. ANNUAL EMISSION OF SO_2 IN TONS PER YEAR FROM AREA SOURCES IN NYC DURING 1965 BY BOROUGH

	BRONX	BROOKLYN	STATEN ISLAND	MANHATTAN	QUEENS
DOMESTIC FUEL					
Bituminous Coal	238	144	14	346	81
Anthracite Coal	1506	1854	82	2193	470
Distillate Oil	5612	20498	1212	777	17549
Residual Oil	42048	45457	2874	77718	23404
Natural Gas	2	9	2	1	6
TOTAL	49406	67962	4184	81035	41510
COMMERCIAL-GOVERNMENT					
Bituminous Coal	375	236	38	375	112
Anthracite Coal	519	840	378	804	394
Distillate Oil	2189	6490	655	1395	4791
Residual Oil	12513	35054	1412	16611	23006
Natural Gas	1	2	-	2	2
TOTAL	15597	42622	2483	19187	28305
INDUSTRIAL FUEL					
Bituminous Coal	750	789	38	750	563
Anthracite Coal	-	-	-	-	-
Distillate Oil	273	1073	263	408	567
Residual Oil	3398	22759	2608	6508	16196
Natural Gas	-	1	-	1	1
TOTAL	4421	24622	2909	7667	17327
POWER PLANTS					
Bituminous Coal	-	14406	13367	84228	44791
Residual Oil	22552	45683	678	34027	60182
Natural Gas	3	-	-	7	9
TOTAL	22555	60089	14045	118262	104982
TOTAL FUEL					
Bituminous Coal	1363	15575	13457	85699	45547
Anthracite Coal	2025	2694	460	2997	864
Distillate Oil	8074	28061	2130	2580	22907
Residual Oil	80511	148953	7572	134864	122788
Natural Gas	6	11	2	11	18
TOTAL	91979	195294	23621	226151	192124
REFUSE DISPOSAL	207	830	4	772	103
MOBILE SOURCES					
Gasoline	364	549	80	633	1060
Diesel	200	308	58	304	627
TOTAL NON FUEL	771	1687	142	1709	1790
GRAND TOTAL	92750	196981	23763	227860	193914

TABLE 7. PERCENTAGE OF SO_2 EMITTED FROM EACH FUEL TYPE IN EACH BOROUGH OF NYC

Fuel Type	Bronx	Brooklyn	Queens	Manhattan	Staten Island
Bituminous coal	1.45	8.61	32.53	37.26	70.80
Anthracite coal	2.16	1.34	0.39	1.31	1.29
Distillate oil # 4	8.60	13.91	10.26	1.13	5.99
Residual oil # 6	87.18	75.69	56.05	59.88	21.53
Natural gas	0.01	0.01	0.01	0.01	0.01
Gasoline	0.39	0.29	0.48	0.28	0.22
Diesel	0.21	0.15	0.28	0.13	0.16
TOTAL	100.00%	100.00%	100.00%	100.00%	100.00%

TABLE 8. EMISSION OF SO_2 FROM AREA SOURCES IN NYC DURING 1965 BY FUEL TYPE

FUEL TYPE	TOTAL SO_2 EMITTED (ton)	PERCENTAGE
Bituminous coal	161,641	22.0
Anthracite coal	9,040	1.2
Distillate oil	63,752	8.7
Residual oil	494,688	67.5
Natural gas	48	-
Gasoline	2,686	0.4
Diesel	1,497	0.2
	TOTAL	100.0%

TABLE 9. EMISSION OF SO_2 FROM AREA SOURCES IN NYC DURING 1965 BY FUEL USAGE

FUEL USAGE	TOTAL SO_2 EMITTED (ton)	PERCENTAGE
Domestic	244,097	33.2
Industrial	56,946	7.7
Government & Commercial	108,194	14.7
Power Plants	319,993	43.5
Refuse incineration	1,916	0.3
Motor vehicle	4,183	0.6
	TOTAL	100.0%

TABLE 10. LATITUDE AND LONGITUDE, AS WELL AS STACK HEIGHT AND DIAMETER AND EFFLUENT TEMPERATURE AND VELOCITY, FOR POINT SOURCES EMITTING MORE THAN 100 TONS OF SO_2 PER YEAR IN THE NYC AREA

	LOCATION						STACK PARAMETERS			
	LATITUDE			LONGITUDE			Height	Temp.	Dia.	Velocity
Number	(deg)	(min)	(sec)	(deg)	(min)	(sec)	(m)	(k)	(m)	$(m \cdot s^{-1})$
P-1	40	33	43	74	14	50				
P-2	40	35	06	74	12	11	157.89	388.64	5.85	19.51
P-3-1	40	44	10	74	07	25	83.82	435.90	4.75	2.13
P-3-2							83.82	566.56	5.30	2.44
P-3-3							83.82	566.56	5.30	0.61
P-3-4							83.82	424.78	4.79	0.30
P-4	40	44	00	74	06	30				
P-5	40	44	40	74	04	42				
P-6	40	49	55	74	01	20				
P-7-1	40	46	08	73	59	51	160.93	474.82	5.03	7.32
P-7-5							74.98	473.15	4.57	10.36
P-7-7							74.98	473.15	4.57	4.27
P-8	40	46	18	73	59	32				
P-9-1	40	42	00	73	59	08	117.96	444.24	7.07	3.05
P-9-2							117.96	444.24	7.07	5.79
P-9-3							117.96	444.24	7.07	8.84
P-9-4							117.96	444.24	7.07	3.05
P-10	40	42	00	73	58	32				
P-11-1	40	43	23	73	58	52	115.21	458.14	6.58	5.79
P-11-2							115.21	458.14	6.58	6.71
P-11-3							115.21	458.14	6.58	6.10
P-11-4							115.21	458.14	6.58	5.79
P-12	40	44	45	73	58	40	120.09	488.72	6.10	3.05
P-13-1	40	44	56	73	58	29	146.30	438.12	6.22	3.96
P-13-2							146.30	438.12	6.22	5.18
P-13-3							146.30	435.34	6.10	3.96
P-14-1	40	45	16	73	56	57	156.97	416.44	7.19	10.67
P-14-2							156.97	416.44	4.18	33.53
P-15	40	45	58	73	57	17	158.50	464.26	4.88	10.67
P-16-1	40	47	00	73	55	02	96.01	419.22	4.11	13.72
P-16-2							96.01	419.22	4.11	16.76
P-17-1	40	47	46	73	55	02	89.61	454.25	6.52	5.79
P-17-2							89.61	454.25	6.52	5.49
P-17-3							89.61	454.25	6.52	4.88
P-17-4							89.61	454.25	6.52	5.79
P-17-5							89.61	454.25	6.52	5.79
P-18	40	53	18	73	55	42	102.41	424.78	5.97	6.71
P-19	41	15	12	73	58	06	143.26	497.06	2.65	26.21
P-20-1	40	36	08	73	40	10	106.68	405.32	3.11	18.59
P-20-2							76.20	408.10	4.88	2.74
P-21	40	44	40	74	04	42	67.97	435.90	4.88	6.71

(continued)

TABLE 10 (continued)

	LOCATION						STACK PARAMETERS			
	LATITUDE			LONGITUDE			Height	Temp.	Dia.	Velocity
Number	(deg)	(min)	(sec)	(deg)	(min)	(sec)	(m)	(k)	(m)	$(m.s^{-1})$
P-22-1	40	29	25	74	17	05	67.06	444.24	3.51	13.11
P-22-2							67.06	444.24	3.51	14.33
P-22-3							64.01	449.80	3.66	13.72
P-23	40	28	33	74	21	22				
P-24-1	40	38	18	74	13	29	68.58	399.76	3.66	4.57
P-24-2							68.58	402.54	3.66	9.14
P-25	40	36	29	73	46	30	81.08	410.88	3.96	7.32
P-26	40	49	24	73	39	43	75.29	408.10	3.96	18.59
P-27-1	41	15	12	73	59	05	74.68	419.22	4.88	4.88
P-27-2							53.34	433.12	1.98	4.57
P-27-3							53.34	433.12	0.98	18.59
P-27-4							61.87	433.12	2.71	24.08
P-27-5							65.53	419.22	3.96	9.14
C-1	40	53	43	74	04	42				
C-2	40	47	51	73	59	58	36.58	449.80	1.49	11.28
C-3	40	50	11	74	05	09				
C-4	40	46	29	74	08	05				
C-5	40	52	10	74	07	04				
C-6	40	49	35	74	08	05				
C-7	40	51	20	74	11	01				
C-8	40	56	08	74	11	14				
C-9	40	55	47	74	09	53				
C-10	40	55	57	74	09	25				
C-11-1	40	43	17	74	07	51	15.24	537.09	1.49	5.49
C-11-2							15.24	537.09	1.49	5.49
C-12-1	40	42	51	74	08	00	76.20	449.80	1.68	1.83
C-12-2							76.20	345.83	1.68	3.05
C-12-3							76.20	345.83	1.68	4.57
C-13	40	44	25	74	09	58				
C-14-1	40	44	04	74	07	11	30.48	449.80	1.68	6.10
C-14-2							28.96	330.26	2.44	3.96
C-14-3							24.38	330.26	2.44	2.44
C-14-4							30.48	330.26	1.31	6.40
C-14-5							30.48	330.26	1.68	10.97
C-14-6							30.48	330.26	0.40	18.59
C-14-7							30.48	330.26	0.67	10.36
C-14-8							27.432	330.26	2.74	1.52
C-15-1	40	39	24	74	06	45	56.39	477.60	3.05	14.94
C-15-2							56.39	477.60	3.05	14.94
C-16	40	38	40	74	08	59				
C-17-1	40	39	39	74	10	26	36.58	449.80	1.49	30.48
C-17-2							36.58	449.80	1.49	11.28

(continued)

TABLE 10 (continued)

	LOCATION						STACK PARAMETERS			
	LATITUDE			LONGITUDE			Height	Temp.	Dia.	Velocity
Number	(deg)	(min)	(sec)	(deg)	(min)	(sec)	(m)	(k)	(m)	($m \cdot s^{-1}$)
C-18	40	41	37	74	13	49				
C-19-1	40	38	02	74	14	02	39.62	449.80	1.49	6.10
C-19-2							22.86	449.80	1.49	6.10
C-20-1	40	36	53	74	15	36	15.24	449.80	1.01	4.88
C-20-2							9.14	449.80	1.01	2.13
C-21	40	36	29	74	15	57				
C-22-1	40	36	40	74	12	02	73.15	324.70	1.37	10.97
C-22-2							21.95	324.70	0.49	7.62
C-22-3							17.68	310.80	0.49	7.62
C-23	40	35	48	74	12	49				
C-24-1	40	35	38	74	12	49	36.58	449.80	1.83	10.97
C-24-2							39.62	449.80	1.83	15.54
C-24-3							30.48	449.80	1.83	6.71
C-25	40	38	19	74	12	49				
C-26	40	36	40	74	12	02				
C-27	40	35	48	74	16	38				
C-28-1	40	34	46	74	13	10	12.19	530.42	1.19	4.88
C-28-2							12.19	530.42	1.19	3.05
C-29	40	32	31	74	15	44				
C-30-1	40	32	10	74	16	19	91.44	728.36	0.91	22.56
C-30-2							91.44	728.36	0.91	22.56
C-30-3							91.44	329.70	2.19	10.67
C-31	40	32	10	74	16	30				
C-32-1	40	32	00	74	15	44	36.58	449.80	1.49	24.38
C-32-2							60.96	811.20	1.01	1.83
C-32-3							60.96	922.40	1.68	15.24
C-33	40	30	49	74	19	31				
C-34	40	28	19	74	26	00				
C-35	40	27	27	74	20	00				
C-36	40	38	08	74	11	14	60.96	474.82	3.66	3.66
C-37	40	55	26	73	54	43	45.72	477.60	3.05	4.27
C-38	40	59	14	73	53	36				
C-39	41	00	57	73	51	12				
C-40	41	04	34	73	50	04				
C-41-4	40	33	23	74	33	17	30.48	449.80	1.83	6.71
C-41-5							30.48	449.80	1.83	6.71
C-41-6							28.96	1000.24	1.19	1.52
C-42	40	49	55	74	05	36				
M-1	40	53	53	74	08	12				
M-2	40	48	43	73	59	19				
M-3	40	47	41	73	59	59				
M-4	40	51	17	74	03	08				

(continued)

TABLE 10 (continued)

	LOCATION						STACK PARAMETERS			
	LATITUDE			LONGITUDE			Height	Temp.	Dia.	Velocity
Number	(deg)	(min)	(sec)	(deg)	(min)	(sec)	(m)	(k)	(m)	$(m \cdot s^{-1})$
M-5	40	51	20	74	06	17	24.08	449.80	2.59	0.30
M-6	40	51	27	74	06	31				
M-7-1	40	51	34	74	06	44	23.77	449.80	1.80	0.30
M-7-2							23.77	449.80	1.80	0.30
M-7-3							23.77	449.80	1.80	0.91
M-7-4							23.77	449.80	1.80	0.30
M-8-1	40	52	00	74	07	18	22.86	449.80	1.52	6.71
M-8-2							76.20	449.80	3.05	10.67
M-9	40	51	18	74	07	38				
M-10	40	50	47	74	08	18				
M-11	40	49	03	74	08	45				
M-12	40	46	39	74	12	03				
M-13	40	46	35	74	14	25				
M-14	40	44	25	74	13	02				
M-15	40	43	43	74	09	39				
M-16	40	43	54	74	09	00				
M-17	40	43	37	74	09	07				
M-18-1	40	43	23	74	08	54	19.81	449.80	0.98	6.10
M-18-2							15.85	449.80	0.21	6.10
M-19	40	42	30	74	08	05				
M-20	40	41	08	74	12	08				
M-21	40	49	55	74	01	07				
M-22	40	46	29	74	02	47				
M-23	40	46	08	74	04	29	60.96	449.80	2.10	3.66
M-24	40	44	52	74	10	07				
M-25	40	44	10	74	09	53				
M-26	40	44	33	74	09	00				
M-27	40	44	33	74	08	45				
M-28	40	44	33	74	05	50				
M-29	40	44	49	74	01	32				
M-30	40	42	42	74	02	28				
M-31	40	43	43	74	11	01	36.58	449.80	1.49	2.13
M-32	40	39	52	74	12	08				
M-33	40	38	49	74	12	08				
M-34	40	38	12	74	12	35				
M-35	40	37	21	74	19	20	64.01	449.80	2.13	6.10
M-36	40	35	31	74	14	37				
M-37	40	35	06	74	14	04				
M-38	40	34	42	74	13	10				
M-39-1	40	34	04	74	13	23	36.58	449.80	1.49	35.36
M-39-2							16.76	449.80	0.67	23.16
M-40	40	33	47	74	15	17				

(continued)

TABLE 10 (continued)

	LOCATION						STACK PARAMETERS			
	LATITUDE			LONGITUDE						
Number	(deg)	(min)	(sec)	(deg)	(min)	(sec)	Height (m)	Temp. (k)	Dia. (m)	Velocity ($m \cdot s^{-1}$)
M-41-1	40	31	49	74	15	44	44.20	449.80	2.41	24.38
M-41-2							67.06	357.50	0.61	21.95
M-41-3							21.34	1072.52	0.91	20.12
M-42-1	40	31	39	74	15	44	68.58	449.80	1.98	9.14
M-42-2							12.19	449.80	0.91	15.24
M-43-1	40	30	06	74	16	51	56.69	811.20	2.13	14.94
M-43-2							61.57	811.20	1.58	14.63
M-44	40	30	37	74	17	32				
M-45	40	30	17	74	20	28				
M-46	40	30	58	74	22	29				
M-47	40	22	51	74	25	38				
M-48	40	31	08	74	25	38				
M-49-1	40	27	01	74	20	28	30.48	449.80	1.83	7.01
M-49-2							30.48	449.80	1.83	7.01
M-50-1	40	26	00	74	20	41	18.29	299.68	0.27	17.68
M-50-2							42.67	358.62	0.61	14.33
M-51	40	24	09	74	01	20				
M-52	40	27	52	74	00	26				
M-53	40	31	08	74	14	10				
M-54	40	38	19	74	10	20	38.40	491.50	1.46	1.22
M-55	40	36	18	74	02	14				
M-56-1	40	35	00	73	59	59	60.96	652.74	3.32	14.02
M-56-2							60.96	652.74	3.32	14.02
M-57	40	34	36	73	58	52	30.48	530.62	_.29	1.22
M-58	40	38	29	74	02	14				
M-59	40	38	54	74	01	39				
M-60	40	39	04	74	01	25	80.47	499.84	3.93	1.52
M-61	40	39	14	74	01	11	48.77	491.50	1.83	1.52
M-62-1	40	40	10	74	01	07	11.89	572.12	0.91	4.57
M-62-2							11.89	572.12	0.91	4.57
M-63-1	40	39	56	74	00	23	60.96	702.78	3.32	18.29
M-63-2							60.96	702.78	3.32	18.29
M-64	40	40	12	73	59	59				
M-65	40	41	49	74	00	23				
M-66	40	41	49	73	59	51				
M-67	40	41	08	73	59	29	6.10	463.70	0.88	6.10
M-68	40	40	47	74	58	52	36.58	491.50	1.19	2.44
M-69	40	42	37	73	58	25	80.16	463.70	4.33	2.44
M-70	40	43	54	73	57	25	32.00	491.50	3.66	0.30
M-71-1	40	44	04	74	57	17	60.96	697.22	3.32	18.29
M-71-2							60.96	697.22	3.32	18.29
M-72	40	43	37	74	57	17				

(continued)

TABLE 10 (continued)

	LOCATION						STACK PARAMETERS			
	LATITUDE			LONGITUDE			Height	Temp.	Dia.	Velocity
Number	(deg)	(min)	(sec)	(deg)	(min)	(sec)	(m)	(k)	(m)	$(m \cdot s^{-1})$
M-73	40	42	10	73	56	23				
M-74	40	41	49	73	56	15	50.29	586.02	1.01	6.40
M-75	40	40	28	73	53	27	44.20	491.50	1.49	2.44
M-76-1	40	39	28	73	52	06	60.96	658.30	3.32	19.81
M-76-2							60.96	658.30	3.32	19.81
M-77	40	44	04	73	57	44				
M-78	40	42	30	73	50	31				
M-79	40	42	40	73	30	45				
M-80	40	47	16	73	51	03				
M-81	40	42	41	73	55	02	16.76	508.18	0.61	20.42
M-82	40	42	51	73	55	15	32.92	435.90	1.37	1.83
M-83	40	43	17	73	55	15	27.43	49.50	1.37	3.05
M-84	40	43	23	73	55	15				
M-85-1	40	43	47	73	55	02	72.85	725.02	3.11	24.38
M-85-2							72.85	725.02	3.11	24.38
M-86	40	44	56	73	55	15				
M-87	40	44	56	73	55	24				
M-88	40	44	31	73	56	36	45.72	530.42	3.05	0.30
M-89	40	45	08	73	56	50	53.34	502.06	2.71	0.30
M-90-1	40	44	04	74	00	53	60.96	811.20	3.35	14.02
M-90-2							60.96	811.20	3.35	14.02
M-91	40	44	21	74	00	07	36.58	641.62	9.11	0.30
M-92	40	45	37	73	59	59	12.19	491.50	0.91	6.71
M-93	40	45	58	73	59	54				
M-94	40	45	37	73	59	09	118.26	447.02	0.88	3.66
M-95	40	45	47	73	57	33	65.23	524.86	4.88	5.18
M-96	40	51	39	73	55	21	51.82	463.70	2.90	0.91
M-97-1	40	51	49	73	55	07	46.33	811.20	3.05	18.29
M-97-2							46.33	811.20	3.05	18.29
M-97-3							46.33	811.20	3.05	18.29
M-98	40	48	49	73	53	54	38.10	502.62	1.22	3.66
M-99	40	49	14	73	55	56	45.72	613.82	1.98	3.05
M-100	40	48	53	73	53	46	44.77	447.02	1.49	1.22
M-101	40	52	31	73	53	46				
M-102	40	49	14	73	51	12	46.33	811.20	3.02	7.01
M-103	40	41	39	73	38	09				
M-104	40	39	45	73	34	38	30.48	463.70	1.31	6.10
M-105	40	44	04	73	29	35				
M-106-1	40	45	17	73	28	34	41.15	811.20	2.59	32.61
M-106-2							41.15	811.20	2.59	33.83
M-107	40	49	55	73	44	46				
M-108	40	53	41	73	49	51	30.48	816.20	1.58	6.71

(continued)

TABLE 10 (continued)

	LOCATION						STACK PARAMETERS			
	LATITUDE			LONGITUDE						
Number	(deg)	(min)	(sec)	(deg)	(min)	(sec)	Height (m)	Temp. (k)	Dia. (m)	Velocity ($m \cdot s^{-1}$)
M-109	40	55	06	73	52	47	22.86	416.44	1.37	19.20
M-110	40	55	37	73	55	02				
M-111-1	40	59	24	73	53	36	29.87	491.50	2.04	1.22
M-111-2							24.08	491.50	1.89	1.83
M-112	40	59	34	73	40	48				
M-113	41	02	44	73	46	30				
M-114	41	03	18	73	52	33	23.16	558.22	1.22	3.35
M-115	41	05	01	73	52	47	19.81	477.60	1.83	10.06
M-116	41	11	17	73	53	41				
M-117	41	02	10	73	55	24	18.29	477.60	1.92	8.84
M-118	41	02	57	73	57	23				
M-119	41	05	57	74	10	20				
M-120	40	48	49	74	24	58	45.72	449.80	1.83	3.96
M-121	40	48	59	74	25	32				
M-122	40	52	31	74	37	20				
M-123-1	40	42	30	73	58	08	22.86	485.38	1.37	6.71
M-123-2							41.15	456.47	1.52	6.40
M-124	40	40	16	74	19	20				
M-125	40	34	25	74	37	33				
M-126-1	40	27	11	74	29	09	19.20	349.72	0.40	25.91
M-126-2							17.07	349.72	0.79	30.48
M-126-3							45.72	349.72	0.79	30.48
M-127	40	15	26	74	16	06				
M-128	40	36	29	74	26	29				
M-129	40	43	33	73	56	19	60.96	508.18	4.21	0.61
M-130	40	41	49	74	03	32				
H-1	40	53	58	73	58	31				
H-2	40	57	05	74	03	59				
H-3	40	53	12	74	03	22				
H-4	40	53	58	74	14	16				
H-5	40	50	41	74	12	49				
H-6	40	50	47	74	14	53				
H-7	40	49	18	74	14	01				
H-8	40	47	37	74	11	12				
H-9	40	45	47	74	14	33				
H-10	40	45	00	74	14	37				
H-11	40	44	30	74	10	47				
H-12	40	43	43	74	11	03				
H-13	40	42	26	74	13	16				
H-14	40	44	25	74	02	22				
H-15	40	44	15	74	03	03				
H-16	40	43	13	74	04	29				

(continued)

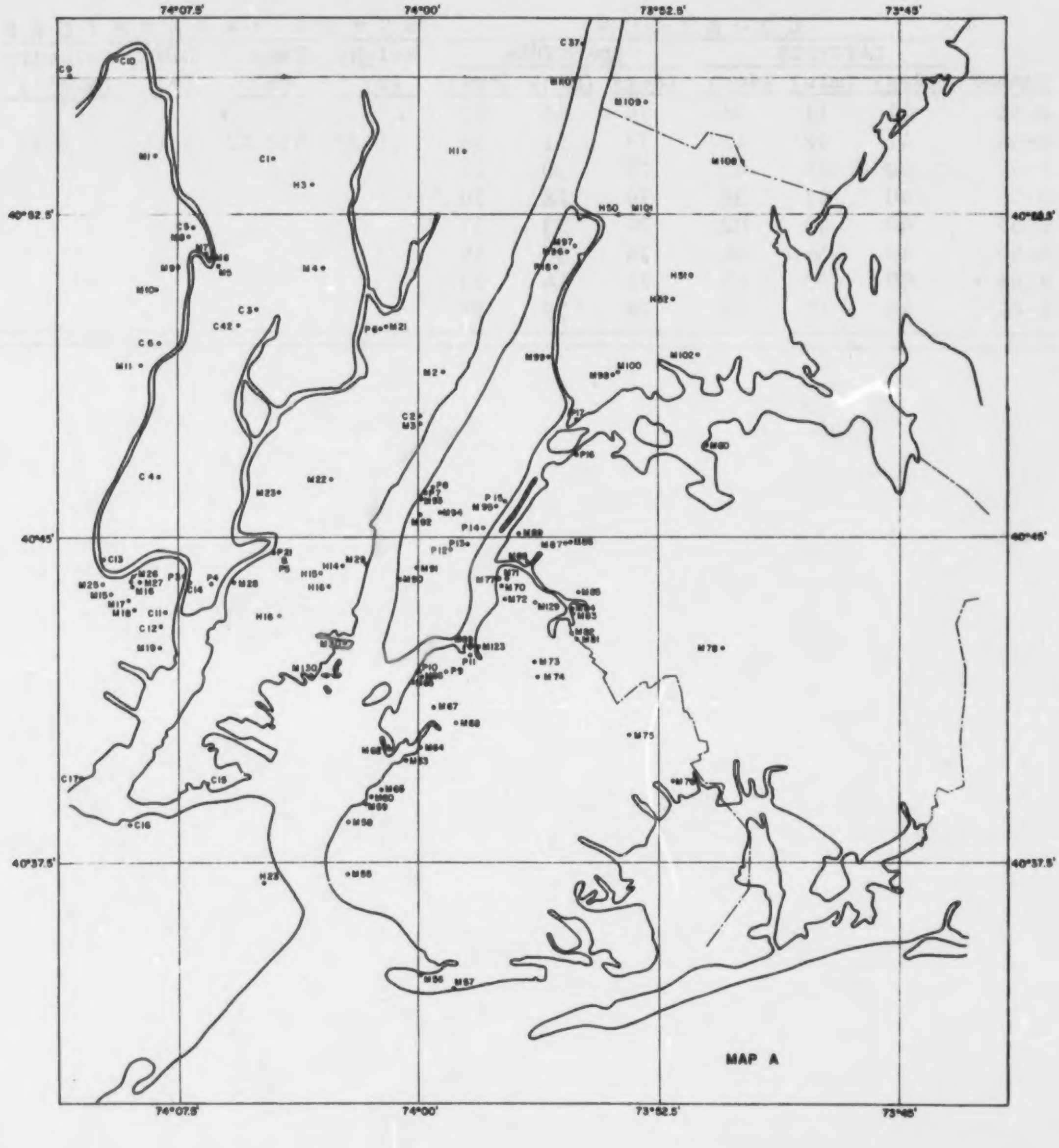
TABLE 10 (continued)

	LOCATION						STACK PARAMETERS			
	LATITUDE			LONGITUDE			Height	Temp.	Dia.	Velocity
Number	(deg)	(min)	(sec)	(deg)	(min)	(sec)	(m)	(k)	(m)	$(m\cdot s^{-1})$
H-17	40	39	24	74	12	43				
H-18	40	40	47	74	24	17				
H-19	40	31	08	74	17	05				
H-20	40	30	00	74	27	00				
H-21	40	29	39	74	27	07				
H-22	40	27	52	74	27	18				
H-23	40	37	10	74	04	56				
H-24	40	35	00	74	58	12	30.48	530.42	2.71	0.61
H-25	40	38	23	74	00	18	45.72	558.22	2.04	1.22
H-26	40	37	52	73	57	36	53.34	502.62	6.46	0.30
H-27	40	39	14	73	56	58	68.58	613.82	5.94	0.91
H-28	40	39	35	73	56	18				
H-29	40	41	18	74	00	26	62.79	491.50	2.71	0.61
H-30	40	40	58	73	59	29				
H-31	40	41	54	73	49	51	51.82	491.50	2.19	1.83
H-32-1	40	43	02	73	48	03	25.30	502.62	0.58	8.53
H-32-2							30.18	503.18	1.52	1.83
H-33	40	44	00	73	44	40	62.79	558.22	2.71	2.74
H-34	40	43	43	73	49	45	53.34	474.26	4.11	0.30
H-35	40	44	21	73	53	36	72.24	491.50	2.13	1.22
H-36-1	40	43	50	73	59	59	55.47	473.71	2.83	1.22
H-36-2							48.77	473.15	2.10	1.22
H-37	40	43	54	73	59	16	62.10	603.26	1.46	1.22
H-38	40	44	25	73	58	48				
H-39	40	44	39	73	59	30	73.46	491.50	1.80	1.22
H-40	40	45	06	73	57	44	122.83	463.70	4.75	0.91
H-41	40	46	25	73	57	58	70.10	463.70	1.89	1.83
H-42-1	40	48	08	73	58	11	44.20	552.66	1.98	1.83
H-42-2							44.50	530.42	1.37	3.96
H-43	40	48	22	73	58	05	36.88	530.42	2.38	1.83
H-44	40	48	31	73	56	50	42.37	491.50	1.83	3.05
H-45	40	49	01	73	57	39	36.27	585.46	3.93	0.30
H-46A	40	30	12	73	57	01	71.63	530.42	3.72	1.83
H-46B	40	49	49	73	55	51	53.34	491.50	2.83	0.30
H-47	40	50	57	73	55	15	48.77	473.15	2.10	1.23
H-48	40	51	39	73	54	40	49.68	463.70	1.68	2.13
H-49	40	51	33	73	53	27	53.34	586.02	1.68	1.22
H-50	40	52	33	73	53	14	25.91	473.15	1.83	3.05
H-51	40	51	07	73	51	25	53.34	463.70	2.71	1.52
H-52	40	50	32	73	50	58	68.58	475.38	3.29	0.61
H-53	41	01	18	73	45	56	33.53	472.04	1.98	1.22
H-54	41	13	59	73	56	23				

(continued)

TABLE 10 (continued)

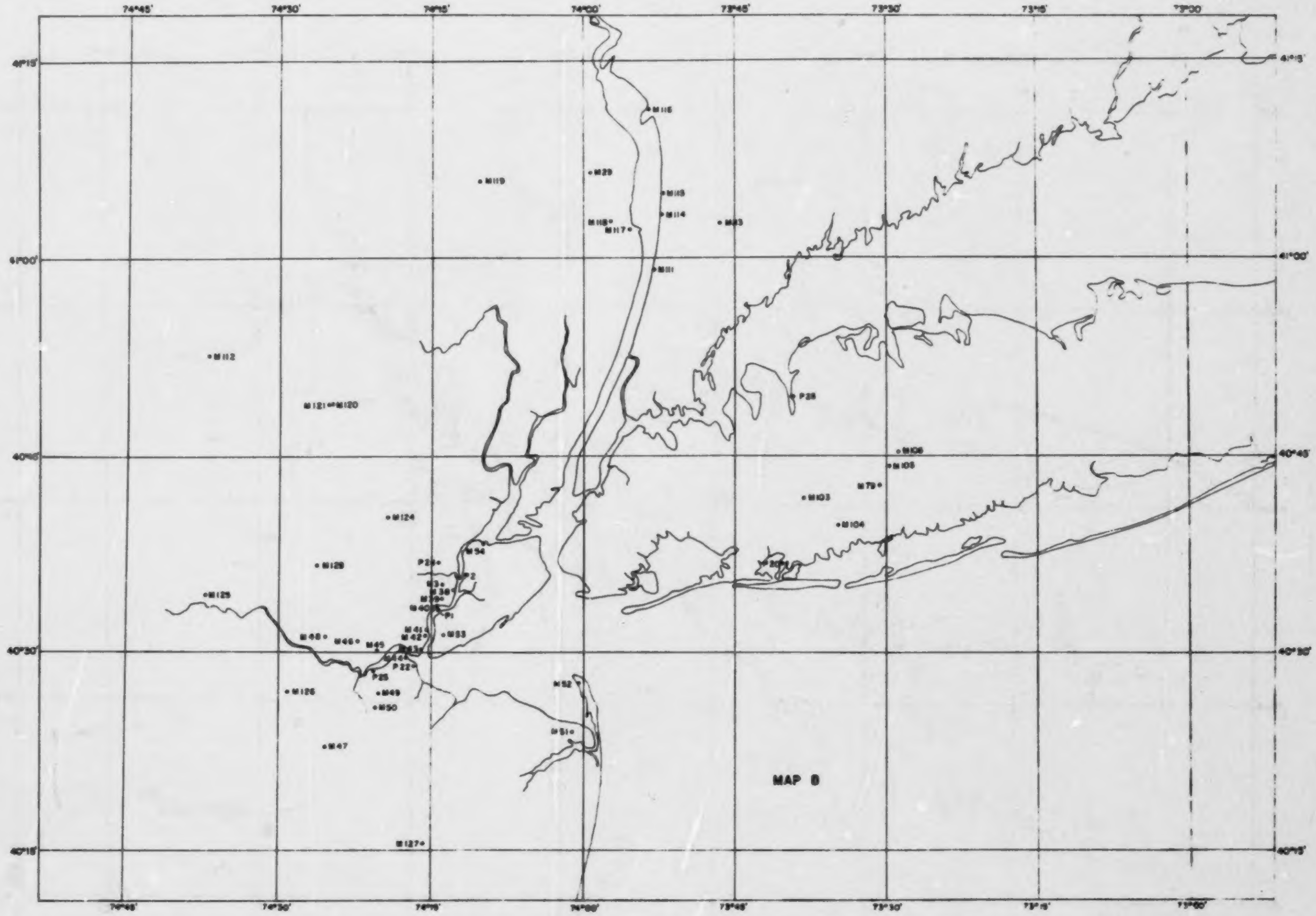
	LOCATION						STACK PARAMETERS			
	LATITUDE			LONGITUDE			Height	Temp.	Dia.	Velocity
Number	(deg)	(min)	(sec)	(deg)	(min)	(sec)	(m)	(k)	(m)	$(m.s^{-1})$
H-55	41	11	36	74	00	00				
H-56	41	02	41	73	52	38	61.87	530.42	3.41	1.22
H-57	40	49	45	74	30	21				
H-58	40	47	38	74	28	20				
H-59	40	40	02	74	33	31				
H-60	40	34	04	74	35	59				
H-61	40	20	43	74	14	23				
H-62	40	17	50	74	59	37				



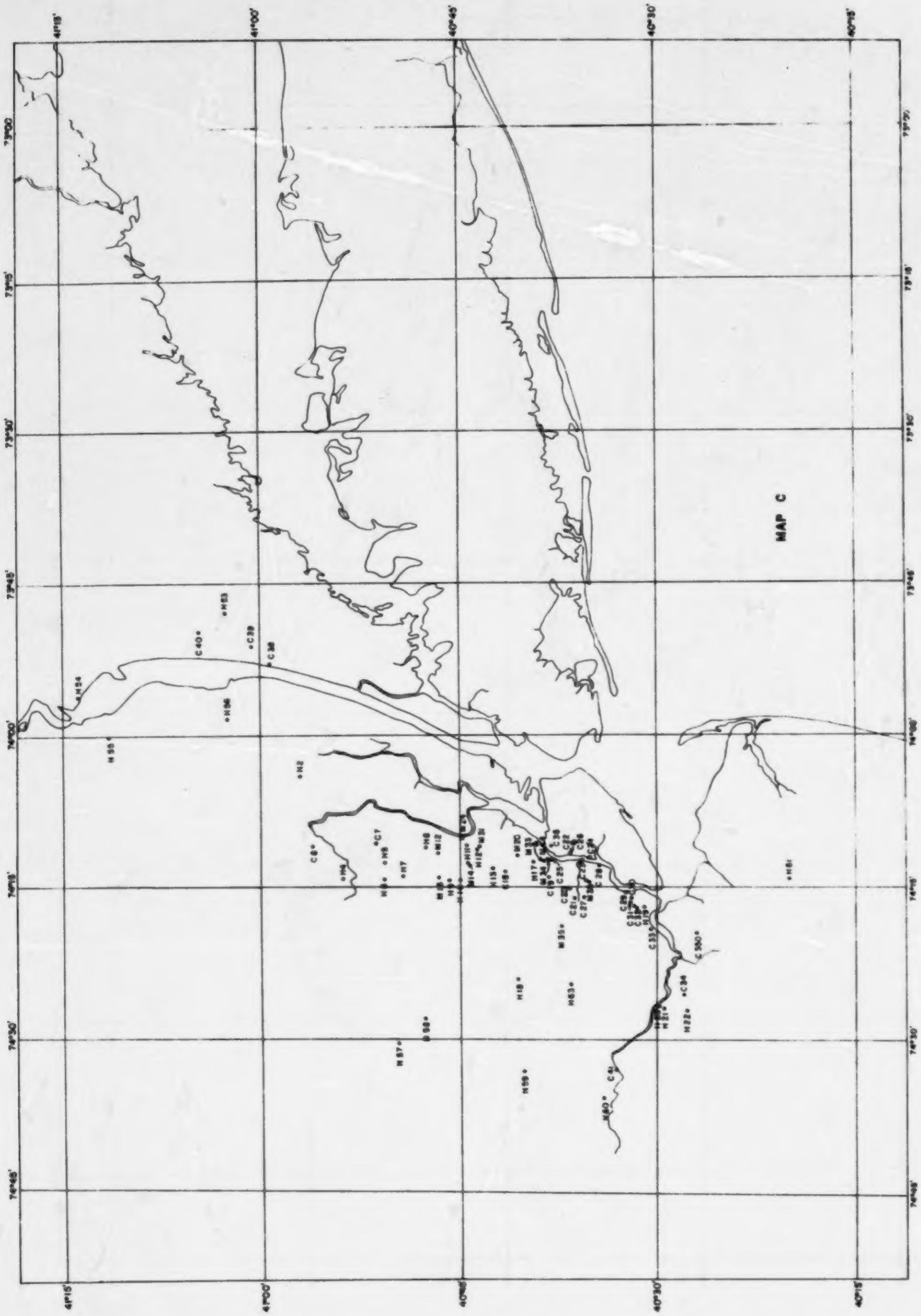
74°07.5'
74°00'
73°52.5'
73°45'
40°52.5'
40°45'
40°37.5'
MAP A

(a)

Figure 2. Location of point sources of SO_2 in NYC area during 1965.


74°45'
74°30'
74°15'
74°00'
73°45'
73°30'
73°15'
73°00'
41°15'
41°00'
40°45'
40°30'
40°15'
M116
M29
M119
M115
M114
M118
M117
M83
M111
M112
M121
M120
P28
M106
M105
M79
M103
M104
P20
M124
M34
P24
M129
M125
M2
M3
M38
M39
M40
P1
M41
M42
M33
M48
M46
M45
M43
M44
P22
P25
M126
M49
M50
M52
M51
M47
M127
MAP 8

(b)


MAP C
41°15'
41°00'
40°45'
40°30'
40°15'
73°00'
73°15'
73°30'
73°45'
74°00'
74°15'
74°30'
74°45'

(c)

section under ANTHROPOGENIC HEAT EMISSION RATES. Given the uncertainties of stack temperature measurements, it might be more accurate to compute all of the plume rise heights using the stack heat emission data rather than the tabulated stack parameters.

The plumes from large point sources are capable of breaking through the top of a surface-based inversion, or of penetrating through one of the weak elevated inversions found over NYC by Bornstein (1968). A procedure for predicting the circumstances during which these breakthroughs will occur can be found in Briggs (1966).

DAILY AND HOURLY EMISSION RATES

Annual emission rates must be converted into hourly emission rates, which are needed as input to urban air pollution models. Point and area sources have different day-to-day and hour-to-hour emission patterns, and the methods used to convert the annual emission rates into hourly emission rates are different for each of the two types of sources.

To obtain data for estimating the hour-to-hour emission patterns from area sources during different seasons, timers were attached to boilers located in selected buildings in the NYC area. Estimates of the diurnal variation of boiler usage were obtained and the resulting data were used by Halpern, Simon and Randall (1971) to relate the number of minutes per day that the boilers were in operation to the degree day value (Figure 3). The degree day value D is computed as follows:

$$D = 65 - \overline{T}, \quad \overline{T} \le 65, \tag{7}$$

or

$$D = 0, \quad \overline{T} \le 65, \tag{8}$$

where $\overline{T}$ is the average daily temperature in units of degrees Fahrenheit (^{o}F). The daily degree values for each day of 1965 and 1966, the period encompassing

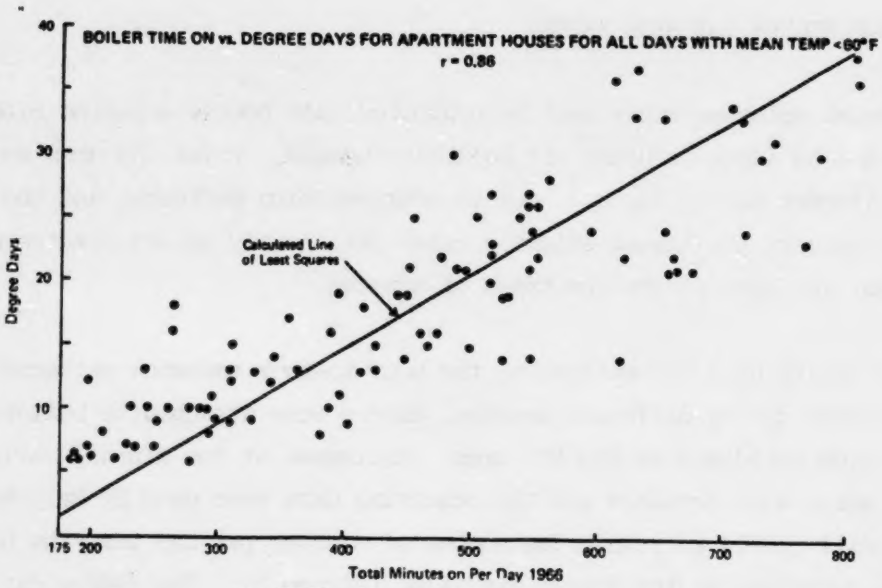


Figure 3. Boiler operating time for apartment houses as a function of degree days as observed in NYC area for 1966 (from Halpern, et al., 1971).

the 12 test periods of the New York City Air Pollution Project, are given in Tables 11 and 12.

The boiler timer data were then used to develop the following equation relating daily emission rates of SO_2 to annual emission rates:

$$S_D = (\frac{0.7}{4871} D + \frac{0.3}{365}) S_A, \qquad (9)$$

where S_D is the daily emission rate of SO_2 from a particular area source on a particular day, and S_A is the annual emission rate of SO_2 from that source.

The above relationship shows that 30% of the annual emission of SO_2 from each area source is due to the production of hot water at a uniform rate throughout the year. The remaining 70% is due to space heating, which is dependent on the average daily temperature. Note that the annual sum of the daily degree day values for NYC is the 4871 appearing in Equation (9).

If S_A was spread uniformly over the year, then on each day 0.27% of the total would be emitted. However, when Equation (9) is used to prorate S_A according to $\overline{T}$ (Figure 4), it is found that the value of $(S_D/S_A) \cdot 100\%$ varies linearly from 1.02% for a $\overline{T}$ of 0^oF to 0.08% for a $\overline{T}$ equal to or greater than 65^oF. Thus the emission on a cold day can be more than an order of magnitude greater than that on a hot day. The same boiler timer data were used to develop the curves of Figures 5(a) and 5(b), which show the diurnal variation of SO_2 emissions from an area source at various average daily temperatures. Note that the values in the figures are for the 2-hour periods used as the time step of integration by Shieh (1969) and thus must be divided in half to obtain hourly emission values.

The hour-to-hour and day-to-day emission patterns for point sources are dependent on the type of point source under consideration. Suggested methods for prorating annual point source emissions into daily and hourly emission rates are shown in Table 13. The suggested methods are based on the following assumptions: (1) manufacturing and industrial operations do not shut down, except for repairs or maintenance; (2) commercial businesses operate only

TABLE 11. DEGREE DAY VALUES AT CENTRAL PARK FOR 1965

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	34	40	28	26	2	0	0	0	0	1	17	28
2	38	36	22	24	0	2	0	0	0	3	26	23
3	37	45	19	23	0	4	0	0	0	3	13	19
4	32	46	14	19	0	2	0	0	0	18	9	20
5	28	42	22	12	0	0	0	0	0	20	20	23
6	25	23	25	11	0	0	0	0	0	17	13	23
7	27	20	18	21	16	0	0	0	0	8	3	30
8	20	10	19	12	11	0	0	0	0	1	12	28
9	17	21	18	15	0	0	0	0	0	4	17	25
10	31	28	22	10	0	0	0	0	0	4	24	20
11	35	22	31	12	0	0	0	0	0	6	18	24
12	33	23	31	5	0	0	0	0	3	3	17	25
13	28	27	28	17	0	2	0	0	8	8	12	21
14	40	37	24	12	2	5	0	0	1	4	20	18
15	50	32	24	14	0	6	0	0	0	0	25	20
16	50	25	21	11	0	7	0	0	0	4	14	21
17	52	29	24	14	0	2	0	0	0	11	21	23
18	46	23	27	19	0	0	0	0	0	9	25	27
19	44	40	21	21	3	0	0	0	0	0	21	32
20	35	43	34	17	0	0	0	0	0	0	19	38
21	34	26	36	11	3	0	0	0	0	0	15	34
22	25	33	32	4	0	0	0	0	0	3	19	30
23	29	43	17	15	0	0	0	0	0	1	19	21
24	37	34	25	17	3	0	0	0	0	11	21	15
25	31	23	26	18	0	0	0	0	4	17	22	12
26	28	35	25	19	0	0	0	0	4	10	15	32
27	31	37	24	13	0	0	0	0	11	10	10	40
28	35	24	23	10	0	0	0	0	12	19	16	30
29	44	-	27	4	5	0	0	5	4	25	28	25
30	49	-	28	0	7	0	0	5	7	14	29	20
31	43	-	30	-	3	0	0	3	-	5	-	8

TABLE 12. DEGREE DAY VALUES AT CENTRAL PARK FOR 1966

DAY	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	8	38	17	23	8	4	0	0	0	14	6	25
2	20	34	17	20	11	2	0	0	0	11	3	32
3	22	31	14	18	8	0	0	0	0	9	13	45
4	26	33	22	19	13	0	0	0	0	1	26	44
5	21	37	23	20	8	0	0	0	0	5	19	34
6	21	41	27	18	0	0	0	0	0	12	19	24
7	21	38	29	15	10	0	0	0	0	6	21	19
8	34	33	32	19	9	0	0	0	0	1	10	9
9	42	28	29	18	19	0	0	0	0	0	5	5
10	26	20	19	19	18	0	0	0	0	2	1	7
11	34	11	19	17	12	2	0	0	0	5	6	17
12	44	13	26	16	10	1	0	0	0	11	15	27
13	42	19	27	23	5	0	0	0	0	10	21	31
14	28	16	23	15	8	0	0	0	0	5	24	30
15	32	24	20	11	3	0	0	0	2	5	22	30
16	46	30	26	11	3	0	0	0	6	3	22	31
17	35	31	21	12	6	0	0	0	1	15	11	22
18	30	30	13	9	5	0	0	0	0	16	9	16
19	32	37	16	14	5	0	0	0	0	8	19	32
20	28	49	16	20	0	0	0	0	3	14	29	34
21	26	40	16	9	0	0	0	0	2	13	24	34
22	29	33	15	6	0	0	0	0	2	9	23	33
23	29	31	19	7	0	0	0	0	2	4	20	36
24	33	30	16	14	0	0	0	0	8	5	12	41
25	38	29	28	2	0	0	0	0	4	8	8	37
26	43	27	25	4	0	0	0	0	9	9	13	37
27	38	26	30	19	0	0	0	0	11	12	15	35
28	51	21	34	24	0	0	0	0	7	7	12	39
29	48	-	27	15	0	0	0	0	5	8	22	27
30	36	-	19	14	1	0	0	0	1	24	25	34
31	44	-	20	-	4	0	0	0	-	18	-	34

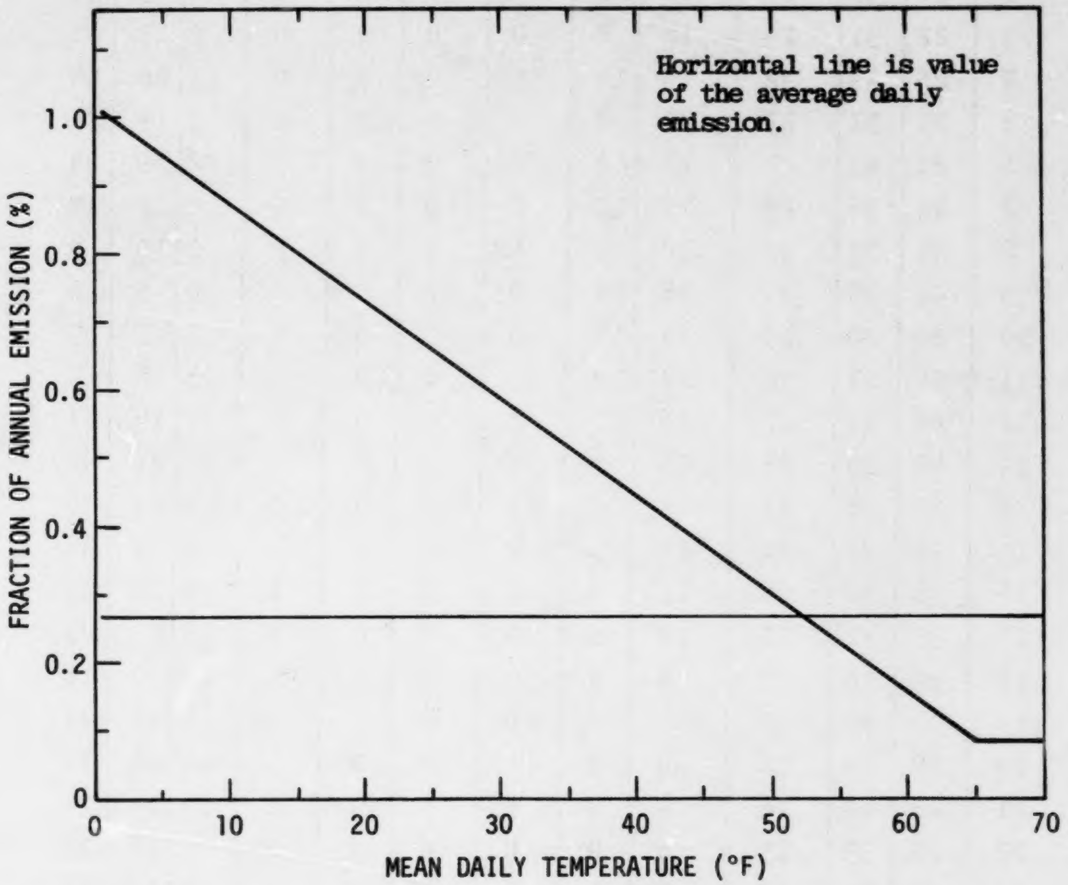


Figure 4. Fraction of annual area source emissions in NYC as a function of mean daily temperature.

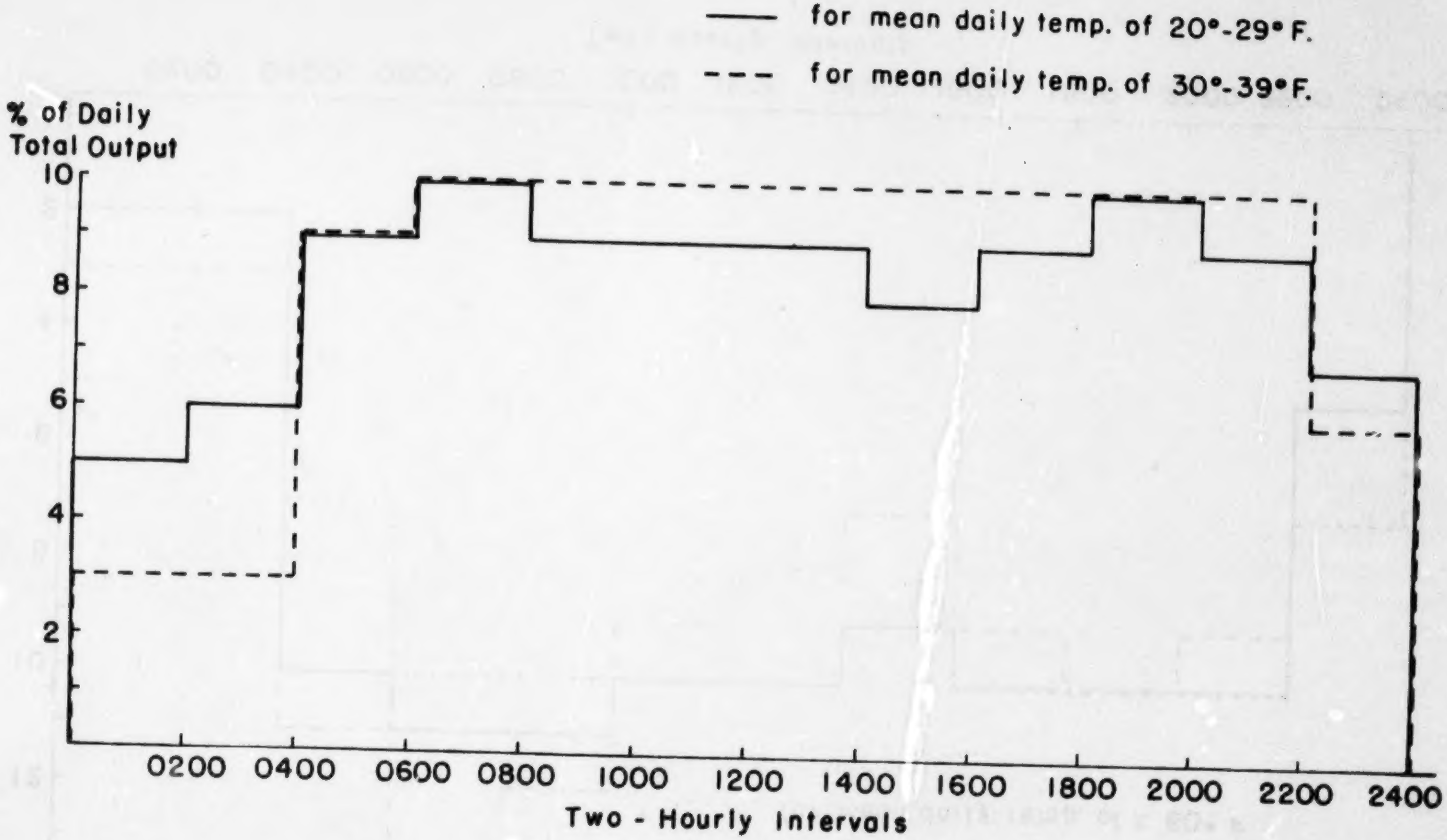
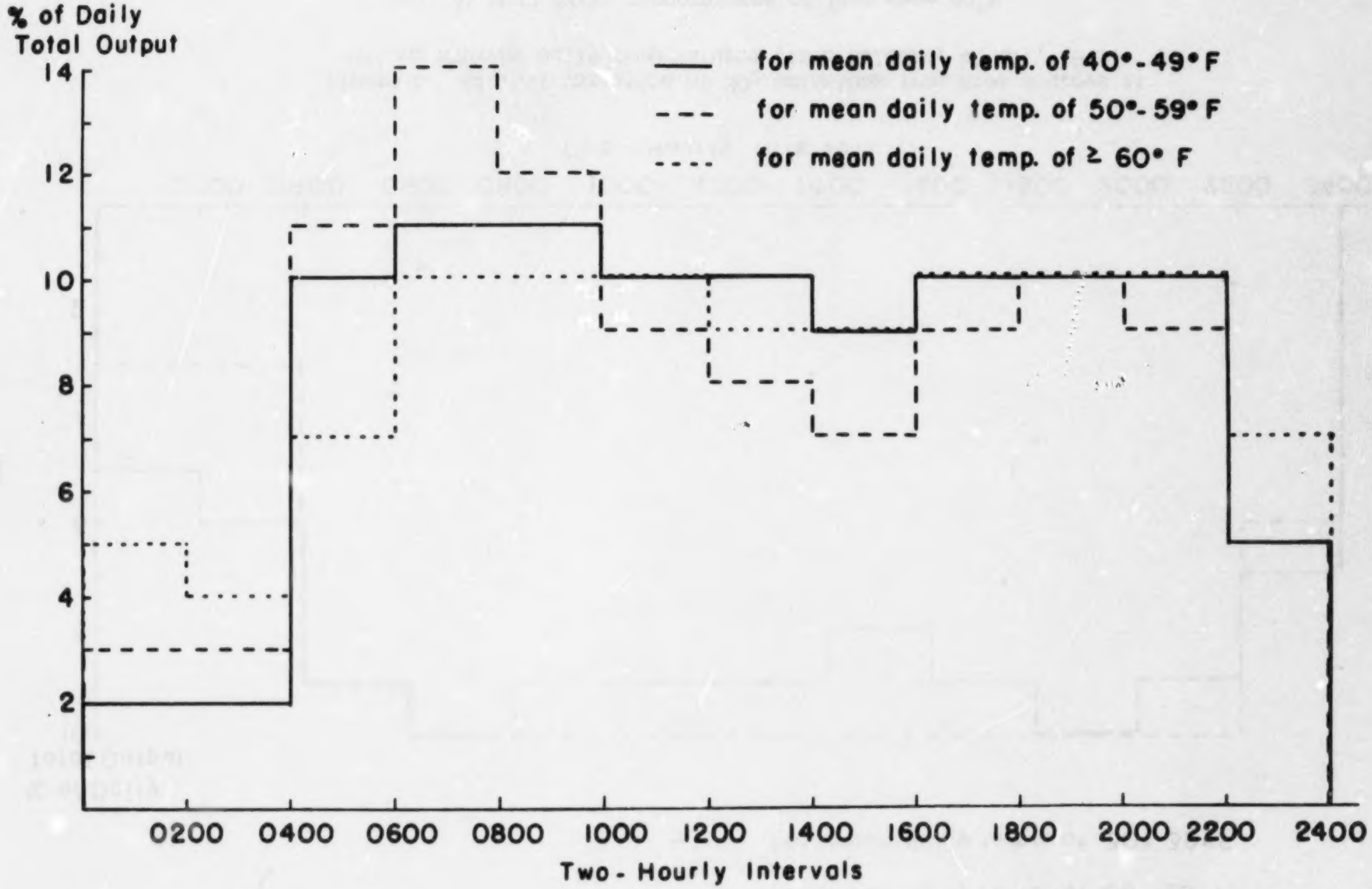


Figure 5. Diurnal variation of SO_2 emissions from area sources at various average daily temperatures (from Halpern, et al., 1971).

(a) At mean daily temperatures of less than 40^{o}F.



(b) At mean daily temperatures of 40°F or higher.

TABLE 13. SUGGESTED METHODS OF PRORATING ANNUAL POINT SOURCE EMISSIONS INTO DAILY AND HOURLY EMISSIONS

Type	Days per Week	Hours per Day
Manufacturing	Uniformly for seven days per week.	Uniformly for 24 hours per day.
Commercial	Uniformly for five working days per week.	Uniformly for eight working hours per day.
Hospitals	Non-uniformly for seven days per week, as given in text for area sources.	Non-uniformly for 24 hours per day, as given in text for area sources.
Power plants	Non-uniformly for seven days per week, as given in text.	Non-uniformly for 24 hours per day, as given in text.

during normal working hours; and (3) hospitals have emission patterns similar to those of residences.

Since SO_2 emissions from power plants are much larger than those from other point sources, an attempt was made during the New York City Air Pollution Project to obtain hourly fuel usage records from such sources in order to compute their actual hour-by-hour SO_2 emissions. The resulting data, when available for the days of the three primary test periods, are given in Volume II.

Estimates of the hourly and daily SO_2 emissions from the remaining power plants can be obtained from Figure 6(a) and 6(b), which show the diurnal variations of the average total electrical load generated by Consolidated Edison during the winter and summer of 1963, respectively.

The average hourly generation rate (horizontal dashed line) for winter was less than that for summer, i.e., 2995 MW versus 3162 MW, due to the production of energy needed for air conditioning. Had the hourly emission rates been assumed to be uniform throughout the year, the average hourly emission would have been 3078 MW (solid horizontal lines).

If the hourly summer and winter rates cited above are each assumed to be valid for 6 months, then it can be shown that 0.281% of the annual power plant emissions will occur on each summer day, while on each winter day, 0.266% will be emitted. Again, had the emission rate been assumed to be uniform throughout the year, the value would have been 0.274%.

Had the hourly emission rates been assumed to be equal throughout the day, then 4.167% of the daily emission rate would have been emitted each hour. Obviously, this is not the case, as shown by the curves of Figures 6(a) and 6(b). However, this value, in conjunction with the average summer and winter hourly megawatt generation values cited above, can be used to compute the summer and winter megawatt values corresponding to the percentages given on the vertical axes in Figures 6(a) and 6(b). These values can be used in conjunction with the average winter and summer daily power plant emission

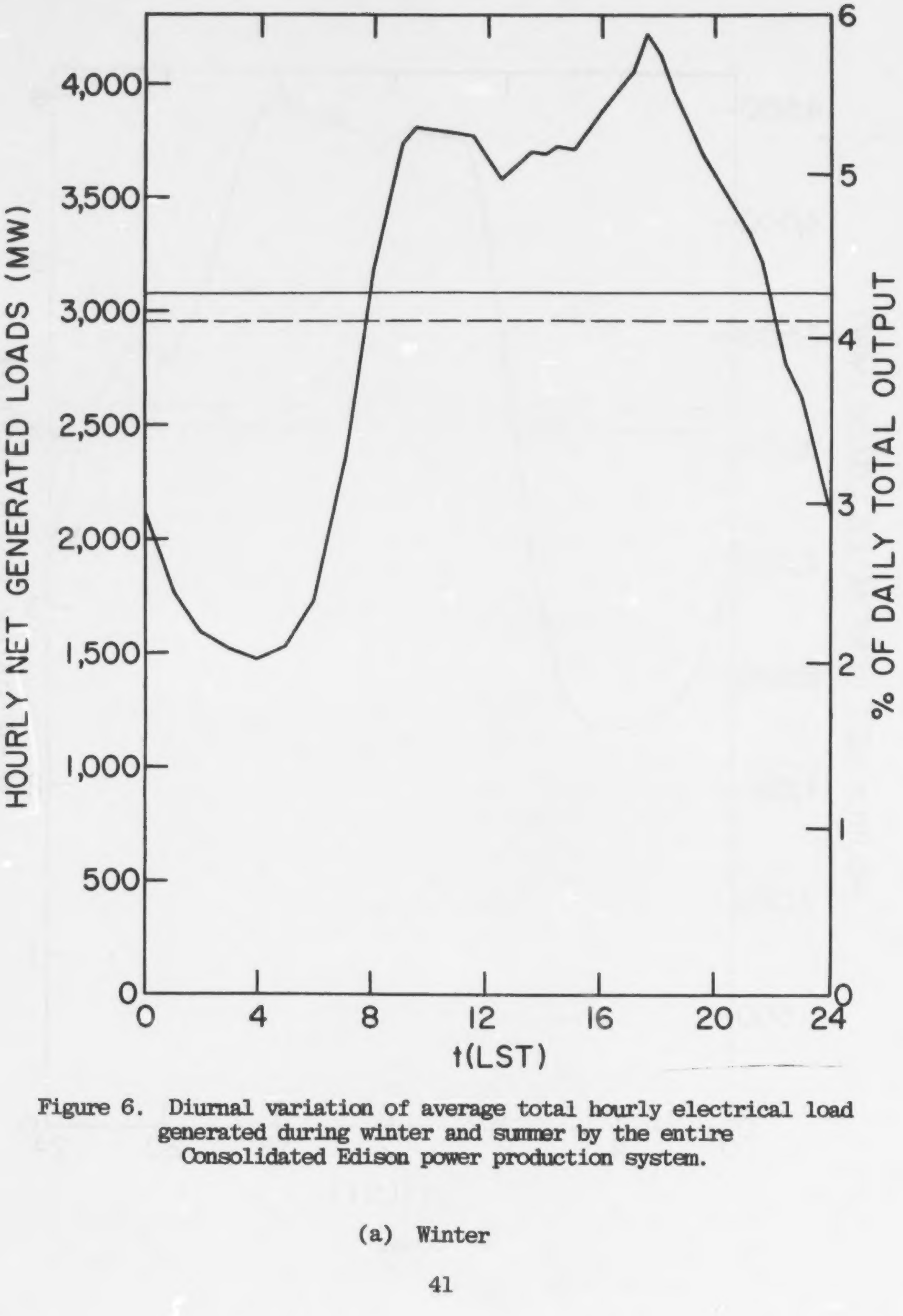
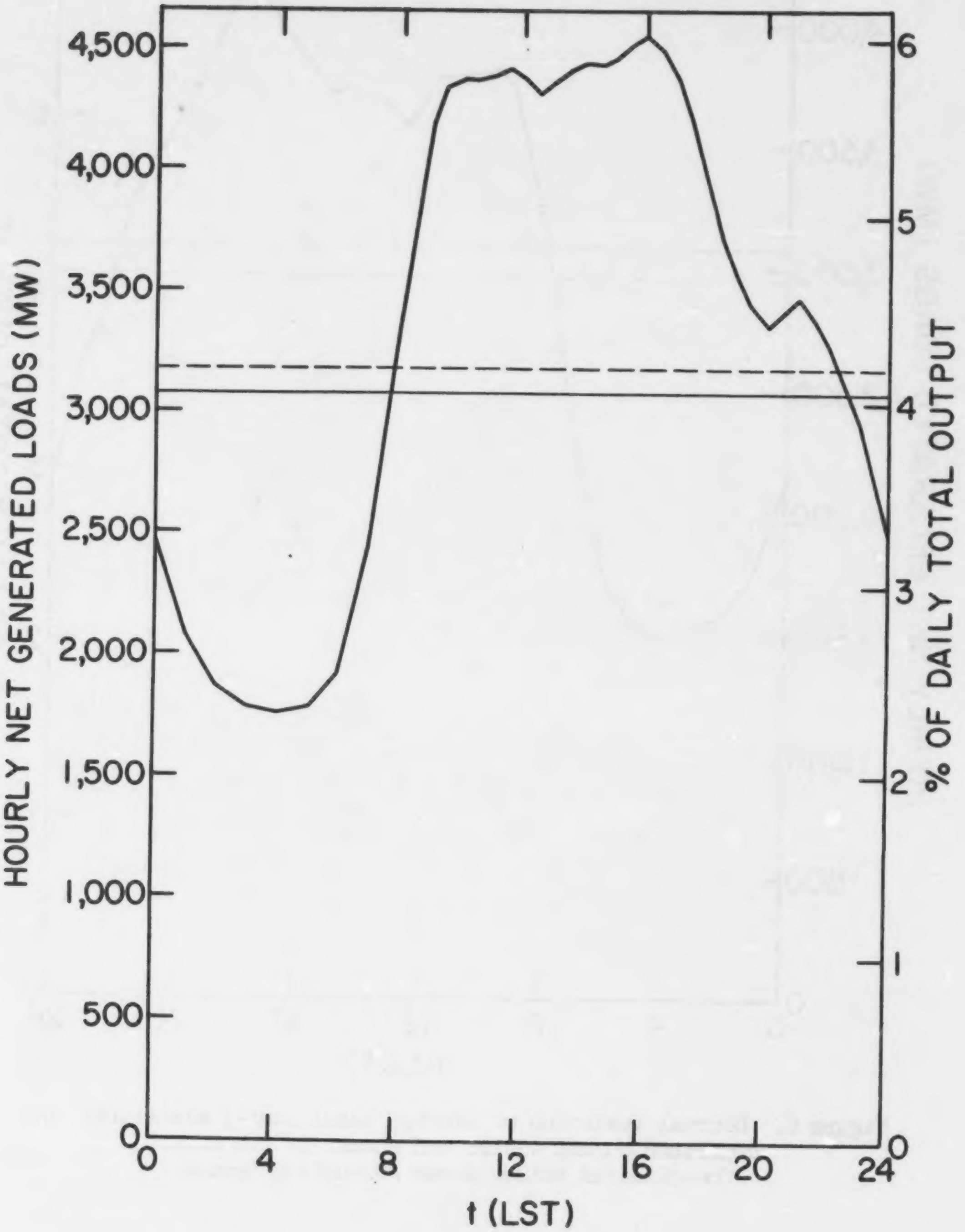


Figure 6. Diurnal variation of average total hourly electrical load generated during winter and summer by the entire Consolidated Edison power production system.

(a) Winter


HOURLY NET GENERATED LOADS (MW)
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
% OF DAILY TOTAL OUTPUT
0
1
2
3
4
5
6
0
4
8
12
16
20
24
t (LST)

(b) Summer

percentages cited above to obtain the desired winter and summer hourly power plant SO_2 emission rates for those sites not having such values tabulated in Volume II.

In summary, information concerning the annual, daily, and hourly emission rates of SO_2 from area and point sources are presented. This information can also be used to obtain the daily and hourly emission rates of anthropogenic heat and moisture from the annual emission rates of these quantities discussed in the following two subsections.

ANTHROPOGENIC HEAT EMISSION RATES

The heat production rates and densities for each fuel type used in NYC are shown in Table 14. The values in the table were obtained by measuring the heat produced by the complete combustion of a unit quantity of fuel in an oxygen-bomb calorimeter under carefully defined conditions. Since the energy contents listed in the table are the available energies (the sensible heat produced upon combustion) as opposed to the thermal contents (the available energy plus the energy required to vaporize the liquid water in the fuel) of the fuel, the latent heat produced by the combustion process is not included in the values computed by the method described in the following paragraph.

The following equation was applied to the SO_2 emissions from each area source grid in the five boroughs of NYC to compute the magnitude of the annual anthropogenic heat production term:

$$H_A = \sum_{i=1}^{7} \frac{S_A \cdot P_i \cdot H_i}{S_i}, \tag{10}$$

where H_A is the annual emission of heat from a particular area source grid in Btu per year, S_A is the annual emission of SO_2 in the grid in tons per year (from Volume II), P_i is the percent of the total SO_2 emission in the grid from the usage of the i-th fuel (from Table 7), S_i is the SO_2 emission factor for the i-th fuel (from Table 5), and H_i is the heat emission factor for the i-th fuel (Table 14).

Note that $S_A \cdot P_i$ gives the annual emission of SO_2 from the i-th fuel in a grid in tons per year, while $S_A \cdot P_i / S_i$ gives the annual usage of the i-th fuel in the grid. This procedure, in which the values of P_i were kept constant in each borough, was used because the usage of each fuel in all of the area source grids was not available, as indicated in Section 1 under LIST OF ARCHIVED DATA. Where the values were available, a random check showed that the magnitudes of P_i in a given borough were within ±5% of the mean values used in Equation (10).

Results from the computation are tabulated in Volume II for: (1) the 1-mile by 1-mile grid; (2) the 0.5-mile by 0.5-mile grid; and (3) those point sources in the inventory for which fuel usage data was available.

In a typical dwelling, anywhere from 60 to 85% of the sensible heat produced by combustion is used for space heating. The remaining energy is exhausted through the chimney. However, space heating is performed mainly to overcome the loss of energy to the atmosphere through walls and windows. Thus all of the energy produced by area source combustion processes has been assumed to mix directly into the atmosphere. Breakdown of the area source anthropogenic heat emission rates by borough, fuel type, and fuel source are given in Tables 15, 16, and 17.

The procedure defined in Equation (10) could only be used for those point sources having available fuel usage data. In order to estimate the heat production due to combustion for the remaining point sources, regression equations were developed between the annual heat and SO_2 emissions for those point sources having available fuel usage data. These resulting correlations are shown in Figures 7(a) – (d) for power plants, hospitals, commercial establishments, and manufacturing concerns, respectively. These correlations are less than unity because the various point sources within each type do not all use the same kind of fuel. Point sources having their annual heat emissions so estimated are shown in Volume II with an asterisk next to their site number.

TABLE 14. ENERGY CONTENT OF FUELS USED IN NYC

FUEL TYPE	DENSITY (lb/unit)	ENERGY CONTENT (Btu/unit)
Bituminous coal	-	14,500 Btu/lb
Anthracite coal	-	13,500 Btu/lb
Grade #4 oil	7.6 lb/gal	145,000 Btu/gal
Grade #6 oil	8.1 lb/gal	150,000 Btu/gal
Natural gas	0.052 lb/ft^3	1,025 Btu/ft^3
Gasoline	6.9 lb/gal	138,000 Btu/gal
Diesel	6.9 lb/gal	131,000 Btu/gal

TABLE 15. EMISSION OF ANTHROPOGENIC HEAT FROM AREA SOURCES IN NYC DURING 1965 BY BOROUGH

Borough	Btu/Year	% of Total
Queens	3.5×10^{14}	32
Brooklyn	3.0×10^{14}	27
Manhattan	2.6×10^{14}	24
Bronx	1.4×10^{14}	13
Staten Island	0.4×10^{14}	4
Totals	10.9×10^{14}	100%

TABLE 16. EMISSION OF ANTHROPOGENIC HEAT FROM AREA SOURCES IN NYC DURING 1965 BY FUEL TYPE

Fuel Type	Total Heat Production (10^{13} Btu/Year)	Percentage
Bituminous Coal	15.60	14.0
Anthracite Coal	1.95	1.8
Distillate Oil	21.75	19.6
Residual Oil	38.79	34.9
Natural Gas	17.11	15.4
Gasoline	15.02	13.5
Diesel	0.87	0.8
Total	111.09	100.0%

TABLE 17. EMISSION OF ANTHROPOGENIC HEAT FROM AREA SOURCES IN NYC DURING 1965 BY FUEL USAGE

Fuel Use	Total Heat Production (10^{13} Btu/Year)	Percentage
Domestic	38.67	34.8
Industrial	15.12	13.6
Government-Commercial	6.15	5.6
Power Plants	35.20	31.7
Motor Vehicle	15.90	14.3
Total	111.04	100.0%

$H = 8.37 \times 10^{-4} S - 1.17$

$r = 0.81$

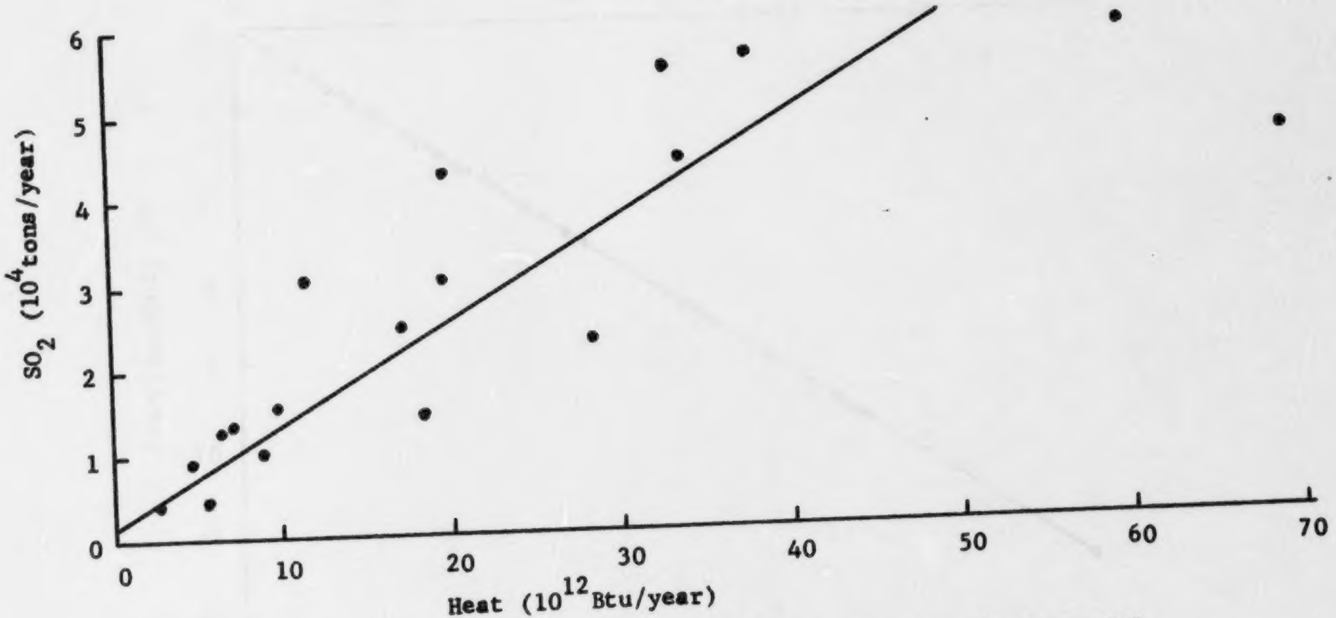
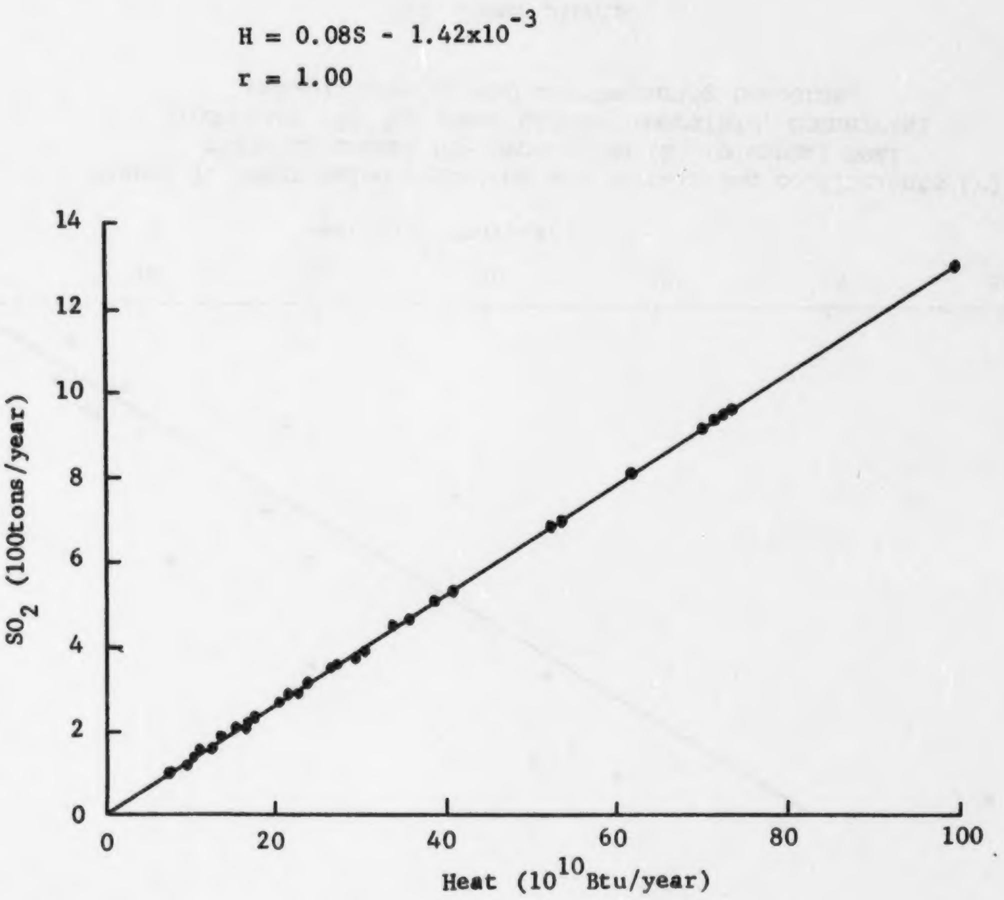


Figure 7. Regression equations and correlation coefficients (r) relating annual SO_2 production (S) to annual heat production (H) for power plants, hospitals, commercial establishments, and manufacturing concerns.

(a) Power plants.



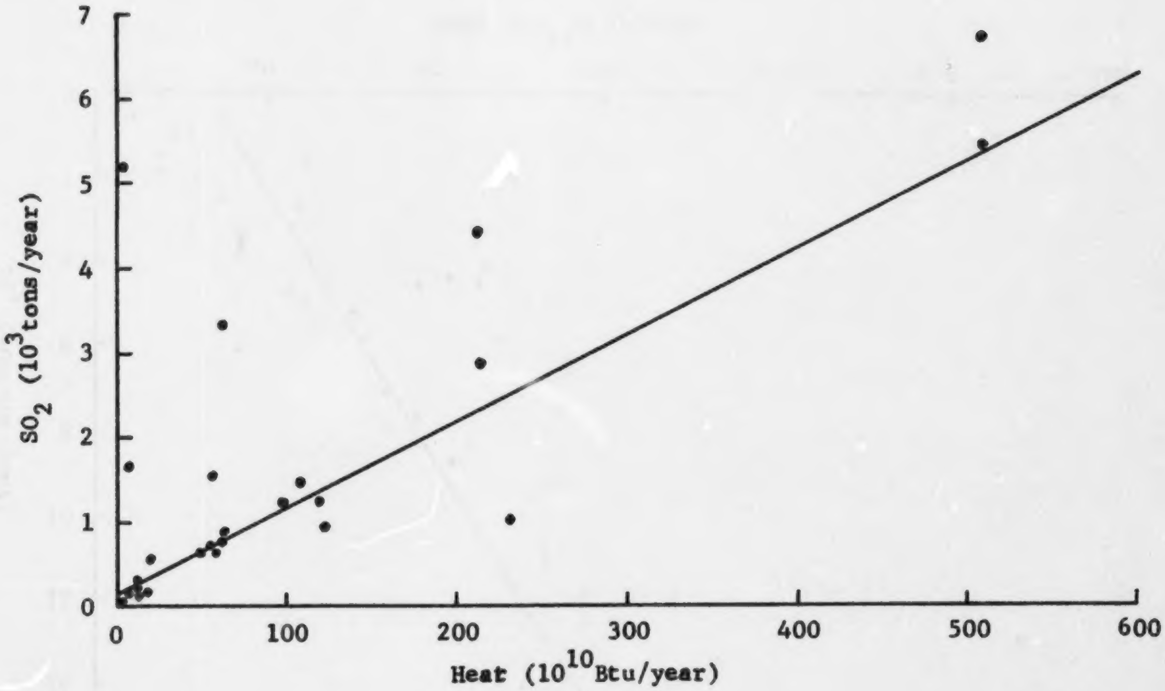
$H = 0.08S - 1.42 \times 10^{-3}$

$r = 1.00$

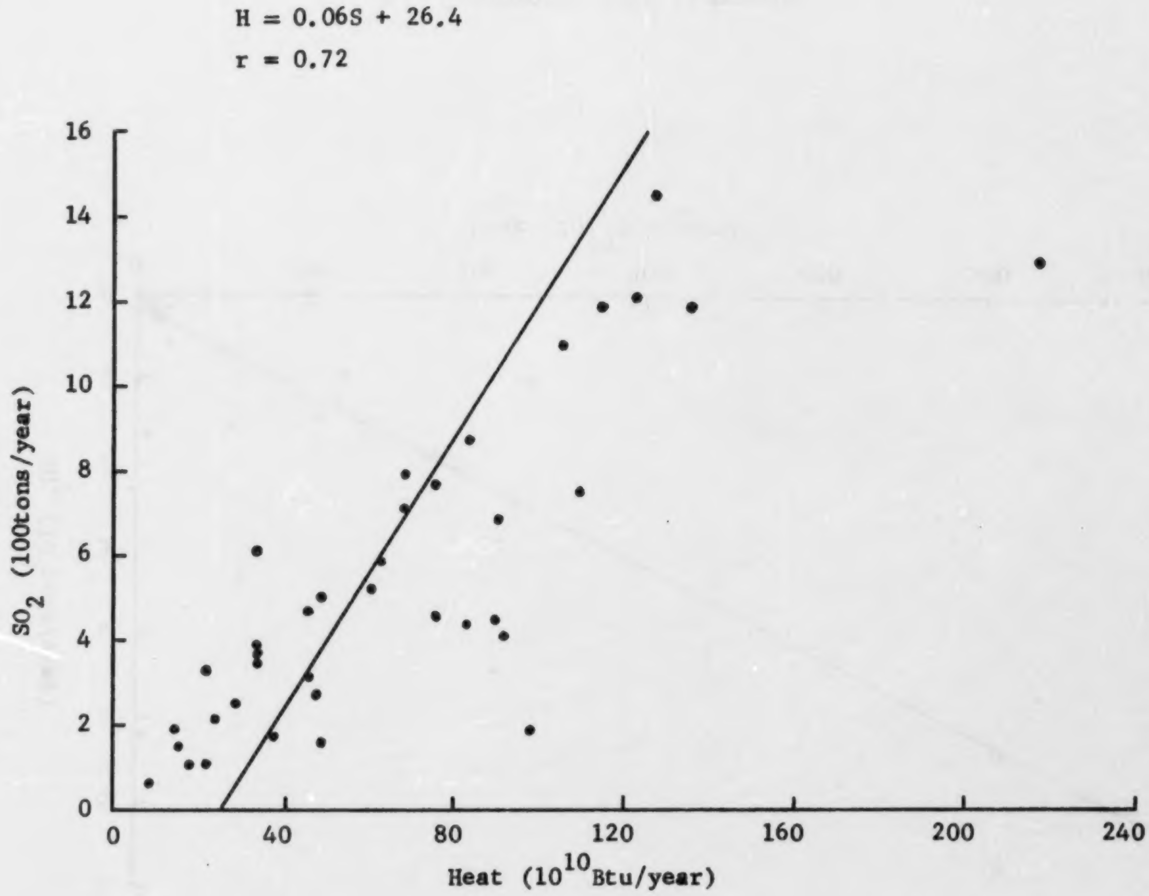
(b) Hospitals.

$H = 0.1S - 25.1$

$r = 0.92$



(c) Commercial establishments.



(d) Manufacturing concerns.

The heat produced by combustion in most point sources is divided as follows: (1) heat exhausted through the stack; (2) heat lost in the condenser system, and drained in the form of water; (3) heat used for power; and (4) heat lost by radiation and other forms of leakage. The average sum of the last three items is generally given as 85% for most types of point sources, and as 90% for power plants.

Thus only either 10 or 15% of the heat computed from Equation (10), and tabulated in Volume II, actually enters the atmosphere in the form of "point source" sensible heat emissions. It is this amount of heat, rather than that computed from the stack temperatures, that could be used in the plume rise computation discussed in this section under ANNUAL SO_2 EMISSION RATES.

The remaining 90% of the energy produced by the power plants, and 85% of the energy produced by the other point sources, eventually does enter the atmosphere. Thus this energy should be added to the "area source" heat emission value (given in Volume II) for the grid area in which the particular point source is located. Note again that the latent energy leaving the stack is not included in the values computed by Equation (10), but is discussed in the following subsection.

ANTHROPOGENIC MOISTURE EMISSION RATES

Production rates of water vapor from the combustion of coal and of gas/oil can be caluclated using Equation (5) and (3), respectively. For coal, 1 gram of hydrogen (H_2) produces 18 grams of water, while y grams of H_2 per mole of gas or oil produces 18 y/2 or 9 y grams of water per mole, where 9 is the ratio of the molecular weights of water and hydrogen.

The composition of natural gas is given in Table 3, as are the water contents by volume and by mass of each component. The "by volume" values were evaluated by multiplying each coefficient of the final term of Equation (5), i.e., y/2, by each percentage in the second column of the table. The "by mass" values were obtained by multiplying each percentage in the second column by the ratio of the total mass of water formed to the mass of the particular hydrocarbon being combusted. Water production factors for each of the fuel types are shown in Table 18, where the liquid water content of each coal was determined by drying under standard conditions for 1 hour at temperatures ranging from 104^{o} to 110^{o}C.

The following equation, analogous to Equation (10), was used for the evaluation of the magnitude of annual anthropogenic moisture production from each of the area sources:

$$M_A = \sum_{i=1}^{7} \frac{S_A \cdot P_i \cdot M_i}{S_i}, \tag{11}$$

where M_A is the annual emission of moisture from a particular area source grid in grams per year, and M_i is the moisture emission factor for the i-th fuel (from Table 18). Note that the values of P_i were again kept constant in each borough, as described in the previous subsection.

Results from the computation are tabulated in Volume II for (1) the 1-mile by 1-mile grid, (2) the 0.5-mile by 0.5-mile grid, and (3) those point sources in the inventory for which fuel usage data was available. Breakdowns of the area source anthropogenic moisture emission rates by borough, fuel type, and fuel source are given in Table 19, 20, and 21, respectively. A summary is presented in Table 22.

Again, the procedure defined in Equation (11) could only be carried out for those point sources for which fuel usage data was available. For the other point sources, the regression equations of Figures 8(a) – (d) were used to estimate the annual anthropogenic moisture emission rates. These correlations differ from those shown in the previous subsection because the various point sources within each type do not all use the same kind of fuel. Point sources having their annual moisture emissions so estimated (see Volume II for the tabulated values) are shown in Volume II with an asterisk next to their site number.

TABLE 18. MOISTURE CONTENT OF FUELS USED IN NEW YORK CITY
(PERCENTS ARE BY MASS)

Fuel Type	H_2 (%)	Gaseous H_2O (%)	Liquid H_2O (%)	Total H_2O (%)	H_2O Released Per Unit
Bituminous coal	5.14	46.26	2.0	48.26	0.4826 lb/lb
Anthracite coal	2.70	24.30	2.2	26.50	0.265 lb/lb
Distillate oil	11.63	104.67		104.67	7.955 lb/gal
Residual oil	11.63	104.67		104.67	8.478 lb/gal
Natural gas		220.80		220.80	0.11 lb/ft^3
Gasoline	15.00	135.00		135.00	9.315 lb/gal
Diesel	15.00	135.00		135.00	9.315 lb/gal

TABLE 19. EMISSION OF ANTHROPOGENIC MOISTURE FROM AREA SOURCES IN NYC DURING 1965 BY BOROUGH

Borough	Production (10^{12} gm/year)	Percentage of Total
Queens	10.13	33
Brooklyn	8.60	28
Manhattan	7.06	23
Bronx	3.99	13
Staten Island	0.92	3
TOTAL	30.69	100

TABLE 20. EMISSION OF ANTHROPOGENIC MOISTURE FROM AREA SOURCES IN NYC DURING 1965 BY FUEL TYPE

Fuel Type	Production (10^{12} gm/year)	Percentage of Total
Bituminous coal	2.35	7.7
Anthracite coal	0.17	0.6
Distillate oil	5.05	16.4
Residual oil	[illegible]	32.3
Natural gas	8.32	27.1
Gasoline	4.59	15.0
Diesel	0.28	0.9
TOTAL	30.69	100.0

TABLE 21. EMISSION OF ANTHROPOGENIC MOISTURE FROM AREA SOURCES IN NYC DURING 1965 BY FUEL USAGE

Source Type	Production (10^{12} gm/year)	Percentage of Total
Domestic	10.91	35.5
Industrial	1.78	5.8
Government & Commercial	4.18	13.6
Power Plants	8.95	29.2
Motor Vehicle	4.87	15.9
TOTAL	30.69	100.0

TABLE 22. SUMMARY OF ANTHROPOGENIC MOISTURE EMISSION FROM AREA SOURCES IN NEW YORK CITY DURING 1965 IN 10^{10} gm/YEAR

FUEL	BRONX	BROOKLYN	STATEN ISLAND	MANHATTAN	QUEENS
DOMESTIC FUEL					
Bituminous coal	0.28	0.17	0.02	0.40	0.10
Anthracite coal	2.89	3.56	0.16	4.21	0.90
Distillate oil	44.45	162.33	9.60	6.16	138.98
Residual oil	82.81	89.53	5.66	153.07	46.09
Natural Gas	37.47	147.17	24.53	24.03	106.47
COMMERCIAL GOVERNMENT					
Bituminous coal	0.44	0.28	0.04	0.44	0.13
Anthracite coal	1.00	1.61	0.73	1.54	0.76
Distillate oil	17.33	51.40	5.19	11.05	37.94
Residual oil	24.65	69.04	2.78	32.72	45.31
Natural gas	14.21	31.60	5.27	36.37	26.44
INDUSTRIAL FUEL					
Bituminous coal	0.88	0.92	0.04	0.88	0.66
Anthracite coal	-	-	-	-	-
Distillate oil	2.16	8.50	2.08	3.23	4.49
Residual oil	6.69	44.82	5.14	12.82	31.90
Natural gas	6.13	15.14	2.52	16.67	12.53
POWER PLANTS					
Bituminous coal	-	18.90	29.28	97.63	83.80
Residual oil	47.02	97.36	1.52	71.07	123.14
Natural gas	47.57	3.95	-	123.47	150.11
TRAFFIC					
Gasoline	61.43	98.67	13.51	106.83	178.96
Diesel	3.76	5.78	1.08	5.71	11.76
TOTAL MOISTURE PRODUCTION					
Bituminous coal	1.59	20.26	29.39	99.35	84.68
Anthracite coal	3.89	5.17	0.88	5.76	1.66
Distillate oil	63.95	222.23	16.87	20.43	181.41
Residual oil	161.17	300.75	15.09	269.67	246.44
Natural gas	105.38	197.87	32.32	200.55	295.55

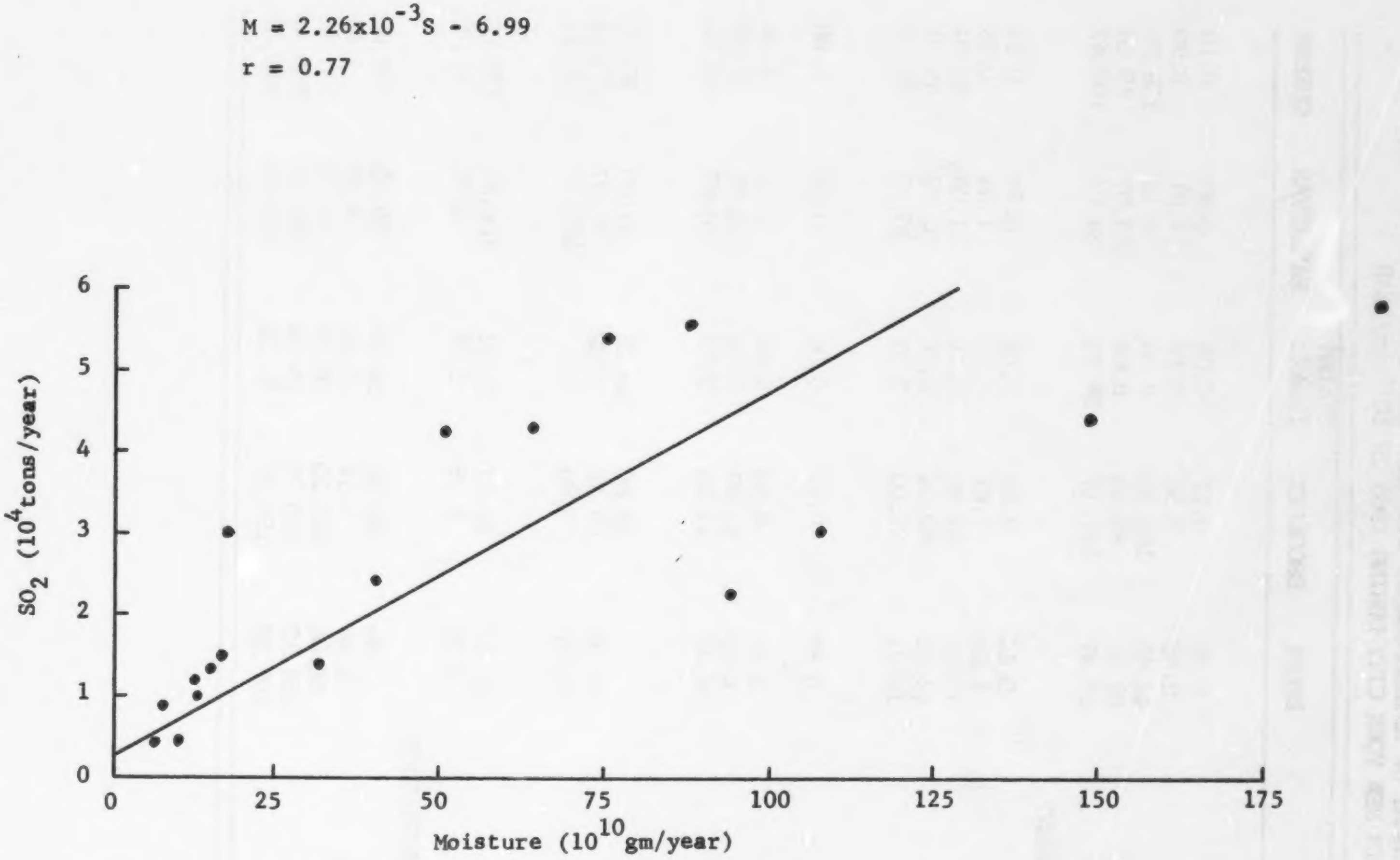
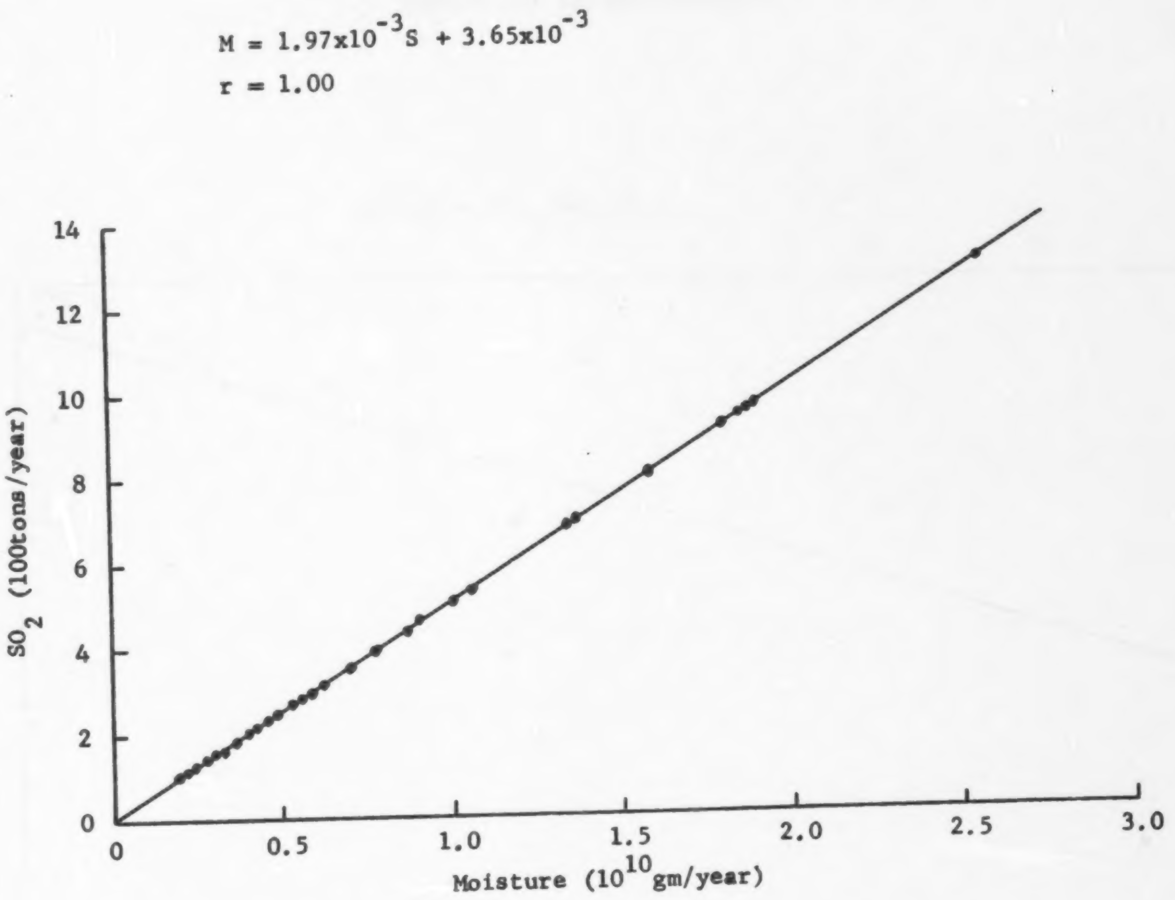
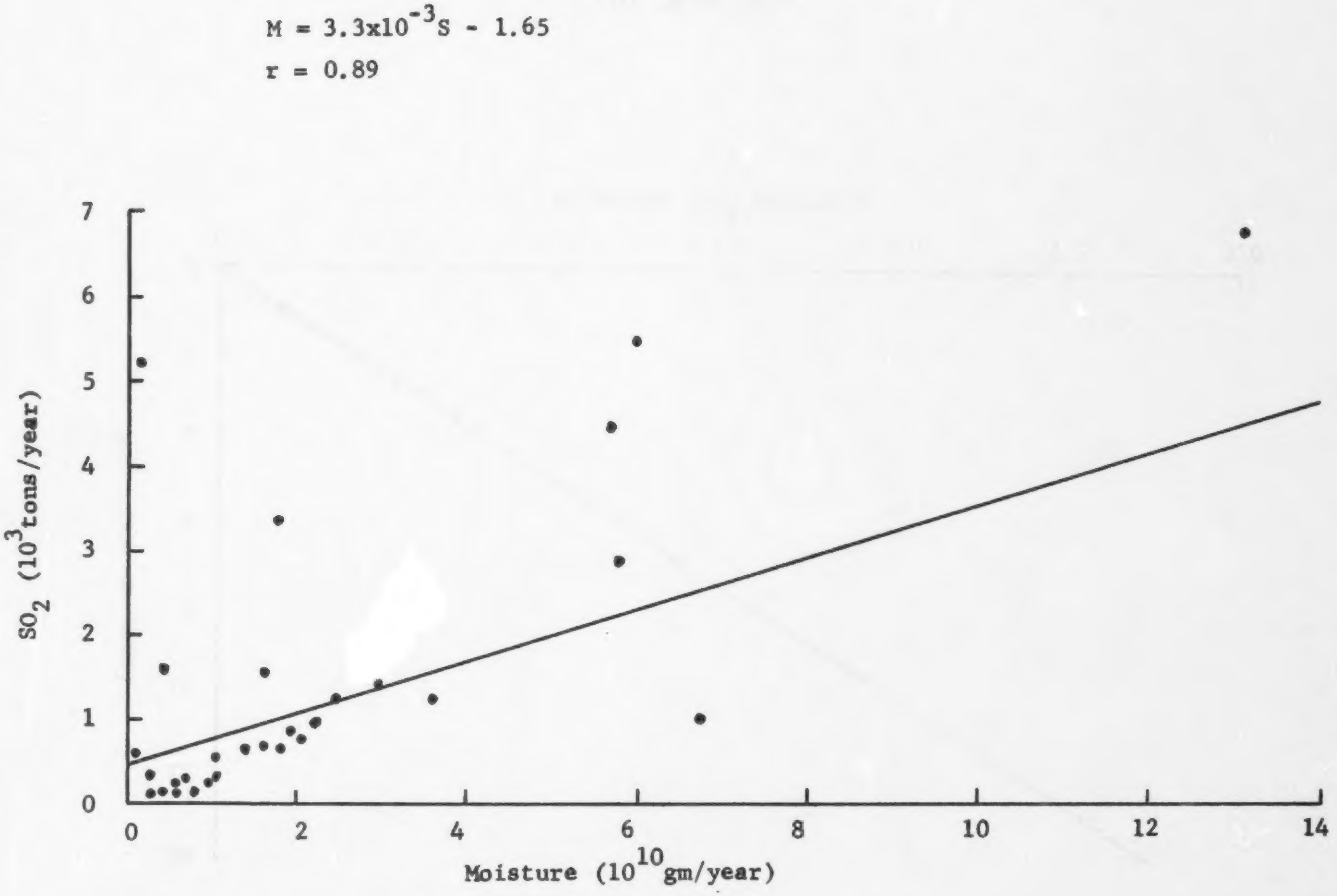


Figure 8. Regression equations and correlation coefficients (r) relating annual SO$_2$ production (S) to annual moisture production (M) for power plants, hospitals, commercial establishments, and manufacturing concerns.

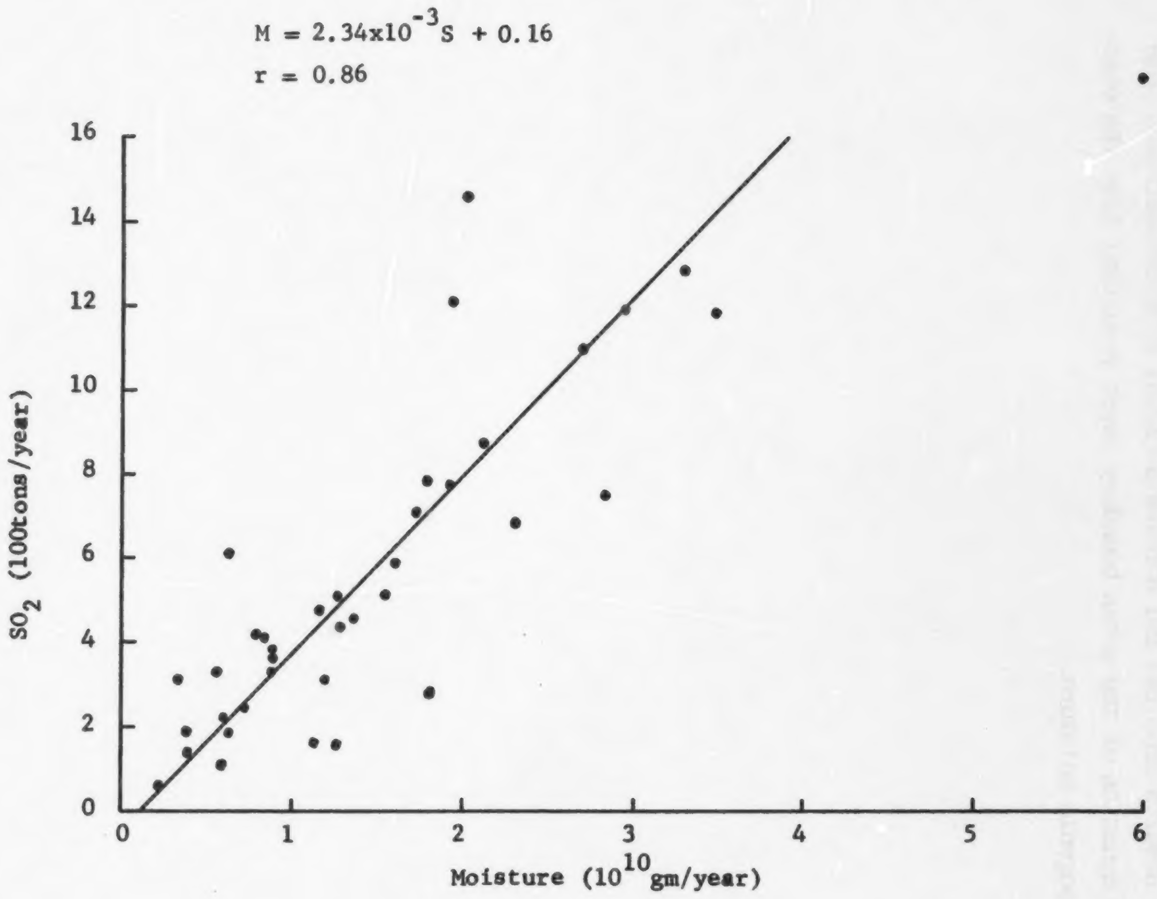
(a) Power plants.


$M = 1.97 \times 10^{-3} S + 3.65 \times 10^{-3}$
$r = 1.00$
SO_2 (100tons/year)
14
12
10
8
6
4
2
0
0
0.5
1.0
1.5
2.0
2.5
3.0
Moisture (10^{10}gm/year)

(b) Hospitals.



(c) Commercial establishments.



(d) Manufacturing concerns.

Whether or not the latent energy associated with these anthropogenic emissions of water vapor is converted to sensible heat as a result of atmospheric condensation processes depends on atmospheric conditions at the time of the emission. Results from Tam and Bornstein (1975) have demonstrated some effects on the dynamics of the urban boundary layer resulting from the emission of anthropogenic moisture.

SECTION 3

AIRCRAFT FLIGHT PROGRAM

FLIGHT PROGRAM DESCRIPTION

The main objective of the aircraft flight program, carried out by the Sign-X Labs of Essex, Connecticutt, was to determine the three dimensional distributions of temperature, humidity, and SO_2 concentrations over metropolitan NYC. The area covered by the flights was roughly circular, approximately 40 km in radius, and centered on Manhattan. The vertical dimensions of the area extended upwards from the surface to about 1 km.

Particular flight patterns followed by the aircraft, as well as the selection of the appropriate aircraft to be flown, were based on the individual mission to be carried out. The missions included determination of heat island characteristics, atmospheric stability, and horizontal and vertical fluxes of SO_2.

Soundings were generally taken during each 2-hour flight as follows: first at rural locations upwind of NYC, then over suburban and urban areas, and finally downwind of the city. In addition to the soundings taken in the vertical plane along the wind, soundings in vertical planes across the wind were also made, bringing the total number of soundings for each flight to about 12. There were generally three such flights per day: one near sunrise, one near midday, and one in the late afternoon.

The optimum flight pattern needed to accomplish the above missions consisted of a series of climbing traverses and spiral descents. The descents were made over an area generally less than 1 km in diameter, using coordinated turns and producing a helical pattern.

When the primary objective of a flight was to obtain the SO_2 flux along and across several significant levels, a series of horizontal traverses normal to the wind were made at the appropriate heights. The first set of traverses was made upwind of the source, and the final set was made at a distance of from 16 to 32 km downwind. The downwind distance divided by the time between the first and last traverses was, ideally, equal to the mean windspeed. When information was desired at distances up to 80 km downwind of NYC, observations were taken at heights up to 2 km above the surface, and a light plane was used instead of a helicopter.

AIRCRAFT INSTRUMENTATION

The primary crafts used in the study were a Brantly B2 helicopter and a Piper PA-12 light plane. On missions where the size and weight capabilities of the B2 were insufficient, a Bell 47J helicopter was used. The Brantly B2 is capable of carrying two persons (a pilot and an observer) and approximately 35 kg of equipment. It is capable of maintaining speeds of from zero to approximately 40 $m \cdot s^{-1}$, and it can fly for approximately 2.25 hours. Although its weight and size capabilities are limited, the specially designed equipment used in the study made its use feasible at a cost significantly lower than that associated with other helicopters.

The Piper PA-12 is capable of carrying three persons and a small equipment load, or two people (pilot and observer) with as much as 70 kg of equipment, and it has about 50% more available space than the B2. Its speed range is from about 29 to 51 $m \cdot s^{-1}$ and its maximum flight duration is about 6 hours. The Bell 47J can carry as much as 160 kg and can fly up to 45 $m \cdot s^{-1}$, but it has a shorter flight duration of about 1.75 hours. More recent models have improved performance capabilities.

Initially, concern existed as to whether transducers could be located in undisturbed air when mounted outside of a helicopter. Since the blades constitute a rotating wind, and not a thrust device, for speeds above about 4.5 $m \cdot s^{-1}$ and at altitudes greater than 3 m, the "downwash" area was located aft of transducers placed ahead of, or on, the forward position of the skid.

Tufts, or short streamers, were placed on a probe attached to, and extending ahead of, the skids. At airspeeds above 13 $m \cdot s^{-1}$, the "downwash" area occurred aft of the cockpit door. During traverses, the helicopters were flown at speeds of approximately 35 $m \cdot s^{-1}$. During soundings, a speed of 27 $m \cdot s^{-1}$ was maintained. On the light plane, the transducers were located in the undisturbed air below the leading edge of the wing and were a considerable distance from the effect of "prop wash."

The Brantly B2 helicopter was selected as the primary vehicle for the small scale studies because of its comparatively low operating costs. However, because of its relatively small size, special attention had to be given to the size, weight, and power requirements of the instrument package. The instrument package also had to be designed so that it could be quickly installed or removed from the helicopter, so as to avoid "down time" charges. The helicopter was leased from a commercial operator, and when not flown on the pollution study, it was used for charter and student instruction. Once the size and weight problems of the Brantly were satisfied, the package could be easily installed in the larger aircraft, i.e., the Bell and the Piper.

The following four measurements were generally made during the 1964 and 1965 flights: temperature, wet-bulb depression, pressure-height, and sulfur dioxide concentration. However, due to a lack of interest in the moisture measurements, wet-bulb observations were generally not taken in 1966.

The temperature sensor consisted of a semiconductor head. The output of the head was a linear function of temperature and had a time constant of approximately 0.2 s. The overall temperature measuring system, consisting of sensor, amplifier, and recorder, had a relative accuracy of 0.2°C and an absolute accuracy of 0.5°C. The wet-bulb depression sensor consisted of a double thermocouple. Each thermocouple had 30 thermofunctions, and one thermocouple was fed with distilled water. The time constant of the wet-bulb depression sensor was 0.1-0.2 s, and its accuracy was 0.2°C.

The pressure-height unit had two aneroid cells driving a potentiometer. The output of the potentiometer was linear with pressure-height according to the standard atmosphere. The time constant of the unit was less than 0.05 ms and its accuracy was about 10 m. The sulfur dioxide unit was of the electroconductivity type, with a time constant of approximately 30 s. However, the electroconductivity method is not specific for SO_2; the main interference is from CO_2. The calibration procedure described in Section 6 under CALIBRATION PROCEDURES includes this effect and allows for a probable accuracy of 10-30%. The SO_2 measurements required a unit separate from the rest of the instrument package, so the unit was located in the baggage compartment of the helicopter or over the baggage compartment in the plane.

The temperature and wet-bulb depression units were located in a double radiation shielded housing mounted to the forward tip of the left skid of the helicopter, or on the junction of the strut and the left wing on the plane. The SO_2 intake was at roughly the same point on the helicopter, but somewhat more inboard on the plane. The pressure-height unit was fed from a point of static pressure known to be unaffected by airspeed.

The outputs of the transducers were amplified and fed to a four-channel rectilinear ink strip chart recorder. The recorder's channel width was 40 mm and its chart speed was either 0.5 or 2.0 $mm \cdot s^{-1}$. Two event-markers allowed for the timing and recording of miscellaneous information, such as location, notes, and photograph number. The recording point and about 6 inches of recordings were visible to the flight observer.

The scales used were as follows: temperature and wet-bulb depression at $0.2^{\circ}C$ per mm; pressure-height at 10 $m \cdot mm^{-1}$; and SO_2 at 2.5 $pphm \cdot mm^{-1}$. There were six temperature scales of $8^{\circ}C$, which overlapped for $2^{\circ}C$; two wet-bulb depression scales of $8^{\circ}C$, which overlapped for $2^{\circ}C$; six pressure-height scales of 400 m, which overlapped for 100 m; and two SO_2 scales of 0-1 and 0-5 ppm.

Analogue records of pressure-height, temperature, wet-bulb depression, and SO_2 concentration versus time were obtained from each flight. An observer's notebook gave location and other information corresponding to the event marks on the chart record. These notes were written on the chart record at the appropriate times, and a map of the flight path was drawn showing the geographic location of the vertical soundings and horizontal and/or climbing traverses.

Prior to and after each flight, laboratory calibrations of pressure-height, temperature, and wet-bulb depression were made. In addition, a comparison was made in the field, prior to and after each flight, between the indicated temperature and a standard thermometer. Flight measurements, conducted to determine effect of dynamic heating, showed that at the flight speeds used (27-35 $m \cdot s^{-1}$) the effect was about $0.3^{o}C$. The SO_2 unit was periodically calibrated in the laboratory for both SO_2 and CO_2, as described in Section 6 under CALIBRATION PROCEDURES.

A miniature version of the Davis electroconductivity unit was required for airborne measurements of SO_2 when the Brantly B2 helicopter was used. A variety of techniques were considered to decrease the size and weight of the unit to acceptable values, but all of the new versions were designed around the same combined absorption and conductivity cell used in the regular Davis instrument. Consideration was given to nonrecirculating systems, and to the use of a venturi or the engine manifold as a source of vacuum. However, both were discarded when calculations and tests showed that a deionizing reservoir with a smaller amount of water and resin would suffice when a suitable pump was used.

The resulting miniature version, therefore, has the identical system components as a Davis instrument. With the exception of the cell, all of the components are small copies of those in the large version. Considerable size and weight reductions were accomplished through the use of a different voltage regulating technique.

Surface pressure readings were obtained during the flight, generally from airports such as LaGuardia, Kennedy, or Newark, so that true heights could be determined from the standard atmosphere and from the record of pressure-height. Indicated temperatures were corrected for dynamic heating, and all variables were corrected, when necessary, according to the various calibrations.

Soundings were plotted manually at the same scales as the chart records to show the vertical distributions of temperature, SO_2 concentration, and wet-bulb temperature (when available). Values obtained from the traverses were also plotted (at their geographic positions) for various significant altitudes.

The helicopter data previously described were used to investigate the horizontal and vertical distribution of temperature (Bornstein, 1968) and moisture (Bornstein, Lorenzen, and Johnson, 1972) in the boundary layer over NYC. In addition, the data were used to validate the URBMET (urban meteorology) boundary layer model of Bornstein (1972a,b, 1975) and Bornstein and Robock (1976).

DATA TABULATION AT SJSU

When the data collected by the NYU group were brought to SJSU, it was discovered that a few of the original helicopter strip charts and almost all of the plotted soundings from 1966 had been lost while the data were stored at NYU. It thus became necessary to repeat the procedures originally carried out by Sign-X to reproduce the plotted soundings. However, some helicopter soundings that had been replotted at NYU during the Project were in the data.

Thus, there are three different sources for the helicopter soundings included in Volume II, as shown in Table 1. The characteristics of the soundings are as follows: (1) "Sign-X" soundings were produced in the manner described in this section under AIRCRAFT INSTRUMENTATION, using data at 25-m intervals in addition to data at various significant levels; (2) "NYU" soundings were constructed during the Project from the original (but now lost) Sign-X soundings by averaging data over 50-m layers; and (3) "SJSU" soundings were produced from the original strip charts using data extracted at 10- or 25-m intervals. After the "SJSU10" (soundings produced from the original strip charts using data extracted at 10-m intervals) were judged to be too irregular, the interval between successive data points was changed to 25 m, thus producing the "SJSU25" soundings listed in the table.

If a Sign-X version of a particular sounding was available, it was included in Volume II; if not, a NYU version of the sounding was included. If neither was available, then the following procedure was carried out to produce the "SJSU" soundings:

(1) Conversion of pressure-height to height above mean sea level.

This was done by knowing the elevations above sea level of the airports at which flights began and terminated. The pressure-height reading obtained when the aircraft was on the runway was set equal to the known elevation of the station above sea level. If the pressure at a particular airport changed with time during a flight, or if the correction was inconsistent for the beginning and terminating airports, then the difference in the correction was prorated over the entire flight. If this procedure could not be followed, i.e., if the takeoff and landing soundings were missing, then the sounding in which the aircraft came closest to the surface was determined, and the bottom of the sounding was assumed to be located at 30 m above ground level. The sounding at 155th Street was used for this purpose whenever possible, due to its location at the Hudson River.

(2) Naming of a sounding.

A list of all of the names applied to the sites at which the soundings given in Volume II were taken is given alphabetically in Table 23, and their locations are shown in Figures 9(a) and 9(b).

(3) Time of sounding.

All times appearing in this report have been corrected to EST. In the absence of information from Sign-X, it was assumed that all times given in the raw data were "time of the realm," i.e., EST or EDT.

TABLE 23. ALPHABETICAL LISTING OF HELICOPTER SOUNDING SITES APPEARING IN FIGURES 9a AND 9b

	SITE		LOCATION					
			LATITUDE			LONGITUDE		
MAP	CODE	NAME	(DEG.	MIN.	SEC.)	(DEG.	MIN.	SEC.)
B	ARM	Armonk	41	07		73	42	
A/B	ATB	Army Terminal Brooklyn	40	45		73	56	
A/B	AST	Astoria	40	47	30	73	54	
A/B	AFB	Atlantic & Flatbush	40	41		73	58	
B	BRK	Barker Pt.	40	51		73	44	
A/B	BAT	Battery	40	42		74	01	
A/B	BAB	Bayonne Bridge	40	38	30	74	08	30
A/B	BAYP	Bayonne Park	40	41		74	07	
B	BYPK	Bay Park	40	38	30	73	40	
A/B	BRP	Bronx River Park	40	50		73	52	
A/B	BCL	Brooklyn College	40	37		73	57	
A		Brooklyn Navy	40	42	30	73	58	
A		Brooklyn VA Hospital	40	39		73	56	
B	CWA	Caldwell-Wright Airport	40	52		74	17	
B	CGR	Cedar Grove Reservoir	40	51	30	74	13	
A/B	CPP	Central Park	40	47		73	58	
B	CLT	Clifton	40	38	30	74	05	
A/B	CLP	Cloves Lake Park	40	37		74	06	
A		Cloisters	40	52		73	56	
B	CWL	Crestwood Lake	40	57	30	73	49	
A/B	CHR	Cypress Hills	40	41	30	73	53	
A/B	EPY	East Parkway	40	39		73	55	30
A/B	ERV	East River	40	44	30	73	58	
A/B	ERP	East River Park	40	43		73	58	
A/B	EIL	Ellis Island	40	42		74	03	
A/B	ECB	Eastchester Bay	40	51	30	73	49	
A/B	FLH	Flushing Airport	40	47		73	50	
A/B	FPK	Forest Park	40	42	30	73	51	
B	FPT	Fox Point	40	54	30	73	35	30
A/B	FWP	Ft. Washington Park	40	50		73	57	
B	GSP	Garden State Pkwy.	40	51		74	10	30
A/B	GAR	Garfield	40	53	30	74	05	30
A/B	GWB	George Washington Bridge	40	51		73	56	30
B		Goethal	40	38	30	74	11	
A/B	GID	Governors Island	40	41		74	01	
A/B	GND	Grand	40	43	30	73	53	
A/B	GVB	Gravesend Bay	40	35		74	01	
A/B	GKL	Great Kills	40	33		74	08	
A/B	GNK	Great Neck	40	48		73	44	
B	HAD	Hadley Airport	40	33		74	26	
B	HOH	Hastings on Hudson	41	00		73	53	
A/B	HAB	Henry Hudson Bridge	40	52	30	73	55	30
A/B	HVR	Hillview Reservoir	40	55		73	52	
A/B	HTL	Holland Tunnel	40	44		74	02	

(continued)

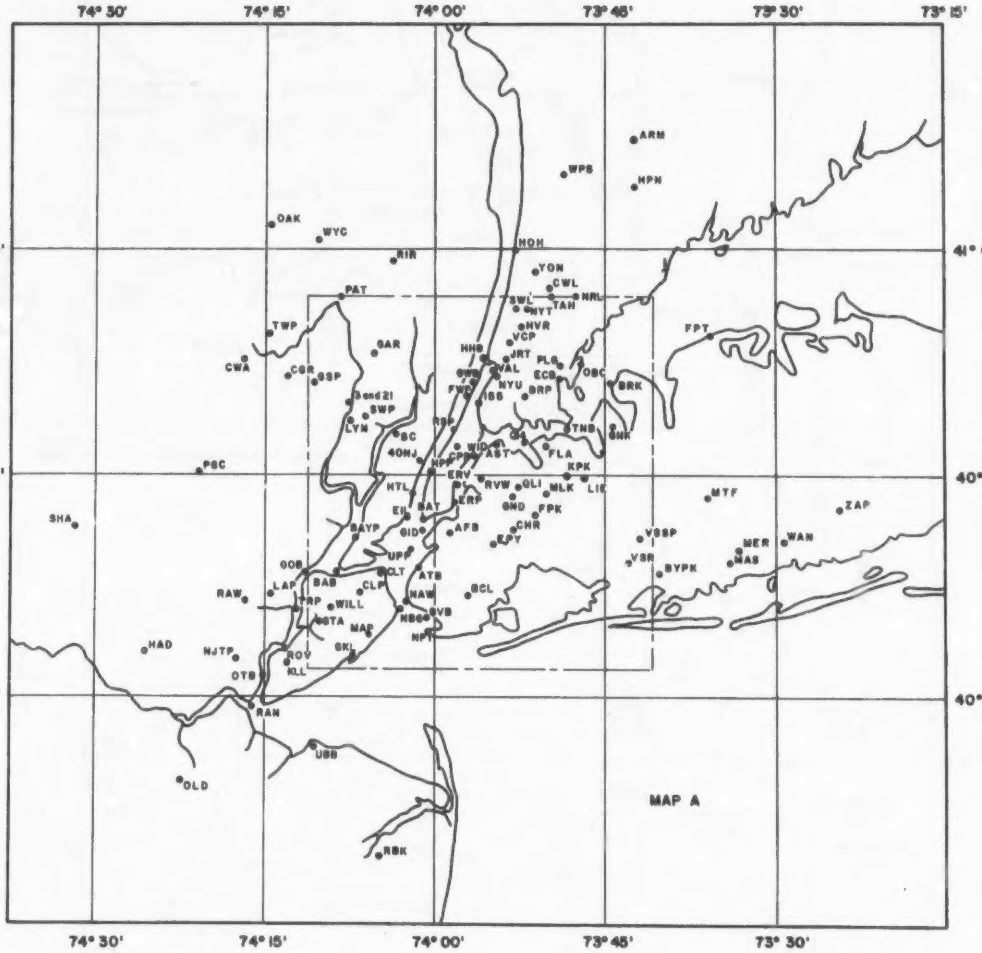
TABLE 23. (continued)

		SITE	LOCATION					
			LATITUDE			LONGITUDE		
MAP	CODE	NAME	(DEG.	MIN.	SEC.)	(DEG.	MIN.	SEC.)
A/B	JRT	Jerome Reservoir	40	53		73	53	30
B	KLL	Kill	40	32	30	74	13	30
A/B	KPK	Kissena Park	40	45		73	48	30
		Lexington Reservoir	41	05		73	48	30
		Lincoln Tunnel	40	48		74	00	
B	LAP	Linden Airport	40	37		74	15	
A/B	LIE	Long Island Expwy.	40	45		73	47	
A/B	LYN	Lyndhurst	40	48		74	07	30
A		McCarren Park	40	43		73	57	
B	MAS	Meadowbrook & Sunrise	40	39		73	34	
A/B	MLK	Meadow Lake	40	43	30	73	50	
B	MER	Merrick	40	40		73	33	
A/B	MAP	Miller Airport	40	34		74	06	
B	MTF	Mitchell Field	40	43		73	36	
		Montclair	40	51	30	74	13	
A/B	NAW	Narrows	40	37		74	02	
A/B	NBG	Narrows Bridge	40	36		74	03	
B	NJTP	New Jersey Turnpike	40	32		74	18	
B	NRL	New Rochelle	40	52		73	47	
A		Newton Creek	40	44	30	73	57	30
A/B	NYT	New York Thoroughway	40	56		73	53	
A/B	NYU	New York University	40	52		73	54	
A/B	NPT	Norton Point	40	34		74	00	30
B	OAK	Oakland	41	01	30	74	14	30
B	OLD	Old Bridge	40	24	30	74	22	
A/B	OBC	Orchard Beach	40	52		73	47	
B	OTB	Outer Bridge	40	31	30	74	15	
A		Overpeck Creek	40	51		74	01	
B	PAT	Patterson	40	57		74	08	
A/B	PLG	Pelham Golf Course	40	52		73	49	
B	PGC	Pleasantdale Golf Course	40	45		74	21	
A/B	Q14	Queens & 14th	40	46		73	51	30
A/B	QLI	Queens & Long Island Expwy.	40	44		73	53	
B	RAN	Raritan	40	29	30	73	57	
A/B	RVW	Ravenswood	40	45		73	57	
B	RAW	Raway	40	36		74	17	
B	RBK	Red Bank	40	20		74	05	
B	RIR	Ridgewood Reservoir	40	59		74	04	
A/B	RSP	Riverside Park	40	47		73	58	
B	ROV	Rossville	40	33	30	74	13	30
A/B	3&21	Route 3 & 21	40	50		74	08	
A/B	SWL	Saw Mill	40	46		73	53	
A/B	SC	Seacaucus	40	48		74	03	30
B	SHA	Sommerset Hill Airport	40	42		74	34	

(continued)

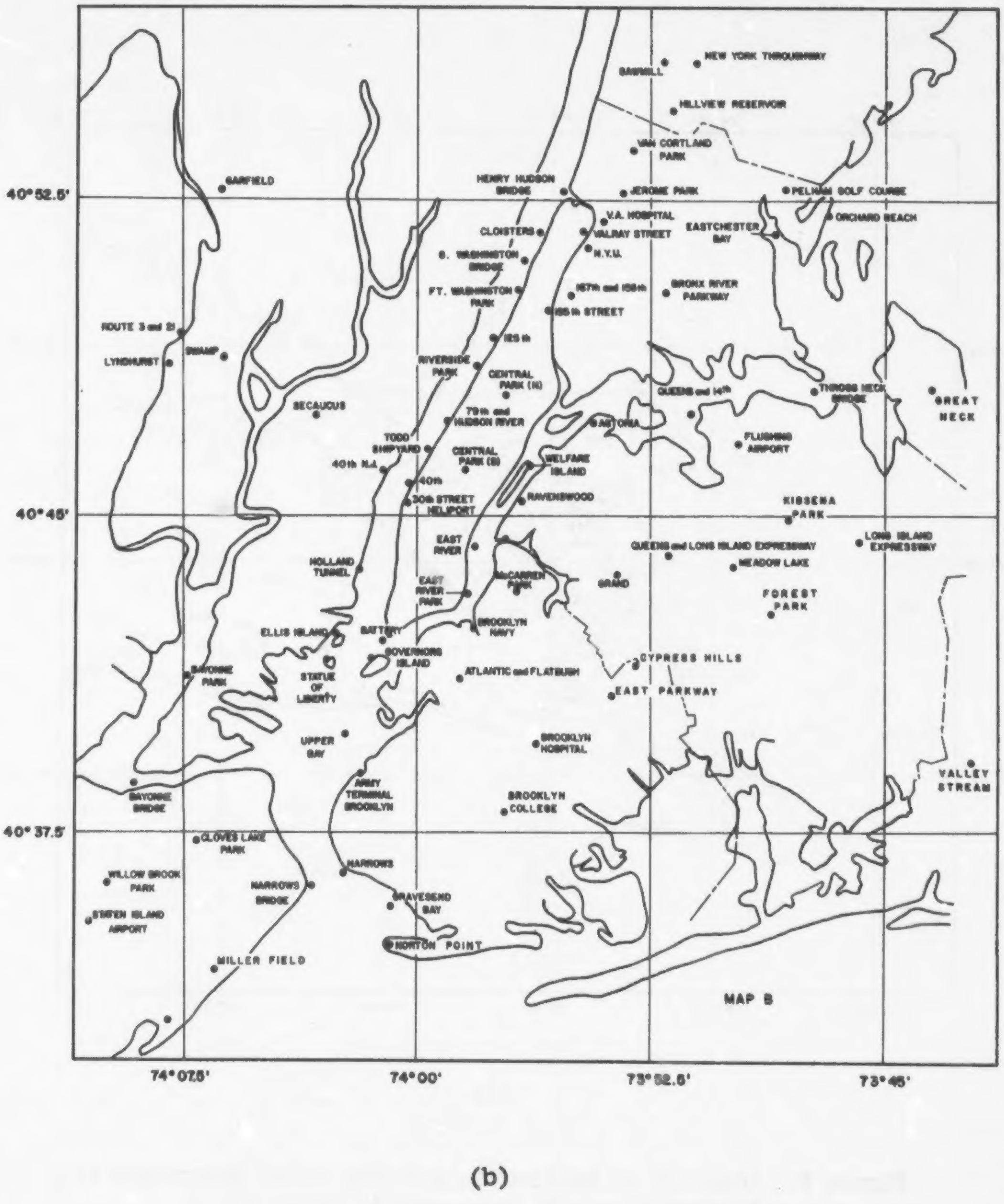
TABLE 23. (continued)

	SITE		LOCATION					
			LATITUDE			LONGITUDE		
MAP	CODE	NAME	(DEG.	MIN.	SEC.)	(DEG.	MIN.	SEC.)
A/B	STA	Staten Island Airport	40	36		74	10	
A		Statue of Liberty	40	31	30	74	03	
A/B	SWP	Swamp	40	49		74	06	30
A/B	TNB	Throgs Neck Bridge	40	33		73	48	
A		Todd Shipyard	40	46		73	59	30
B	TWP	Totoura-Wayne Airport	40	54		74	15	
B	TRP	Tremley Point	40	36		74	12	
B	TAH	Truckahoe	40	56	30	73	50	
B	UBB	Union Beach	40	27		74	11	
A/B	UPP	Upper Bay	40	40		74	02	
A		VA Hospital (Bronx)	40	52		73	54	
A/B		Valley Stream	40	39		73	43	
B	VSSP	Valley Stream State Park	40	41		73	42	
A/B	VAL	Valray Street	40	52		73	55	
A/B	VCP	Van Cortland Park	40	53	30	73	53	
B	WAN	Wantagh	40	41		73	29	
B	HPN	Westchester	41	04		73	43	
A/B	WID	Welfare Island	40	46		73	56	30
B	WPS	White Plains	41	05		73	48	30
A/B	WILL	Willowbrook Park	40	36		74	09	
B	WYC	Wyckoff	41	01		74	10	
B	YON	Yonkers	40	58		73	51	
B	ZAP	Zahs Airport	40	42	30	73	40	
A/B	HPP	30th St. Heliport	40	45		74	00	30
A		40th	40	45	30	74	00	30
A/B	40NJ	40th & New Jersey	40	45	30	73	46	
A		79th & Hudson River	40	47		73	59	
A		125th	40	49		73	58	
A/B	155	155th	40	50		73	56	
A		167th & 155th	40	50	30	73	55	


74° 30'
74° 15'
74° 00'
73° 45'
73° 30'
73° 15'
ARM
WPS
HPN
OAK
WYC
41° 00'
HOH
RIR
YON
CWL
PAT
NRL
SWL
NYT
TAH
HVR
FPT
TWP
VCP
SAR
HHB
JRT
PLG
CWA
CGR
SSP
WAL
ECB
OBC
GWB
NYU
BRP
BRK
FWD
ISS
Sand 21
SWP
LYN
RSP
TNB
SC
GNK
40NJ
WID
CP
AST
FLA
NPP
KPK
PSC
40° 45'
ERV
RVW
GLI
HTL
MLK
LIE
MTF
ZAP
EH
BAT
ERP
GND
FPK
SHA
BAYP
GID
AFB
CHR
VSSP
EPY
WAN
UPP
MER
VSR
MAS
GOB
CLT
SYPK
BAB
ATB
LAP
CLP
BCL
RAW
TRP
HAW
WILL
GSTA
SVB
NBC
MAP
NPT
HAD
NJTP
ROV
SKL
KLL
OTB
40° 30'
RAN
UBB
OLD
MAP A
RBK
74° 30'
74° 15'
74° 00'
73° 45'
73° 30'

(a)

Figure 9. Location of helicopter sounding sites designated by abbreviations or names used in Table 23.


NEW YORK THROUGHWAY
SAWMILL
HILLVIEW RESERVOIR
VAN CORTLAND PARK
GARFIELD
40° 52.5'
HENRY HUDSON BRIDGE
JEROME PARK
PELHAM GOLF COURSE
ORCHARD BEACH
V.A. HOSPITAL
CLOISTERS
VALRAY STREET
EASTCHESTER BAY
G. WASHINGTON BRIDGE
N.Y.U.
FT. WASHINGTON PARK
167th and 158th
BRONX RIVER PARKWAY
155th STREET
ROUTE 3 and 21
125th
SWAMP
LYNDHURST
RIVERSIDE PARK
CENTRAL PARK (N)
QUEENS and 14th
THROGS NECK BRIDGE
GREAT NECK
SECAUCUS
79th and HUDSON RIVER
ASTORIA
FLUSHING AIRPORT
TODD SHIPYARD
CENTRAL PARK (S)
WELFARE ISLAND
40th N.J.
40th
30th STREET HELIPORT
RAVENSWOOD
40° 45'
KISSENA PARK
EAST RIVER
LONG ISLAND EXPRESSWAY
QUEENS and LONG ISLAND EXPRESSWAY
MEADOW LAKE
HOLLAND TUNNEL
McCARREN PARK
GRAND
EAST RIVER PARK
FOREST PARK
ELLIS ISLAND
BATTERY
BROOKLYN NAVY
GOVERNORS ISLAND
CYPRESS HILLS
BAYONNE PARK
STATUE OF LIBERTY
ATLANTIC and FLATBUSH
EAST PARKWAY
UPPER BAY
BROOKLYN HOSPITAL
VALLEY STREAM
BAYONNE BRIDGE
ARMY TERMINAL BROOKLYN
BROOKLYN COLLEGE
40° 37.5'
CLOVES LAKE PARK
NARROWS
WILLOW BROOK PARK
NARROWS BRIDGE
GRAVESEND BAY
STATEN ISLAND AIRPORT
NORTON POINT
MILLER FIELD
MAP B
74° 07.5'
74° 00'
73° 52.5'
73° 45'

(b)

(4) Plotting the sounding.

Draftsmen were instructed to "smooth" the data when tracing a plotted sounding, but they were also told not to change the sounding significantly in the process of smoothing out small perturbations.

(5) Temperature scale.

Electronic drifts of the zero point of the various scales were prorated into the data.

(6) SO_2 scale.

The actual calibration procedures for the Davis instruments are described in Section 6 under CALIBRATION PROCEDURES. Calibration curves (Figure 18, example) were assumed to be represented by the following linear equation

$$S = \frac{R_d - R_w}{a - c(R_w - b)}, \qquad (12)$$

where S is the SO_2 concentration in ppm; R_d is scale deflection caused by the effects of both the ambient SO_2 and CO_2; a, b, and c are constants, determined by the slopes of the calibration curves for each of the Davis instruments in the surface network discussed in Section 6 and for those instruments used in the aircraft; and R_w is the scale deflection due only to the ambient CO_2 and thus is used as the zero point for the SO_2 concentration scale. The values of the three constants for the aircraft Davis instruments changed on July 6, 1966 when Sign-X installed a new cell in the Davis instrument in the helicopter. Equation (12) was used directly on data from the surface network of Davis instruments but it could not be directly applied to the Davis instruments mounted on the aircraft because the aircraft instruments lacked a scrubber (see Section 6, CALIBRATION PROCEDURES). For these data, R_w was assumed to be the smallest scale deflection recorded during a particular flight. This value (R_w) generally occurred in soundings taken at upwind rural sites, and/or in the upper levels of urban soundings, and was generally constant with height over several hundred meters. After R_w was determined, Equation (12) was solved for R_d, which corresponded to a value (concentration) of S of 0.1 ppm. Since the equation is linear, the magnitude of this distance gave the constant scale interval for each 0.1 ppm increase of S for a particular flight.

All of the soundings from the three primary test periods are given in Volume II. The soundings from the remaining periods of Table 1 are at SJSU, but are not included in this report because the lack of time and money prevented their completion.

Additional vertical temperature profiles were obtained from the National Weather Service rawinsonde site at John F. Kennedy Airport (see Figure 14). A summary of the data obtained from these launches is given in Appendix II. These soundings were routinely taken twice a day (at 0615 and 1215 EST) until the end of February 1966, and from then until the end of the Project, two additional launches were taken daily at 0015 and 1815 EST. The lack of data for a particular time indicates that no inversion was present in the sounding below 4 km. Inversions were defined as layers in which temperature either increased with height or remained constant with height. In cases of multiple inversions, only the lowest layer was reported.

SECTION 4

SURFACE WIND DATA

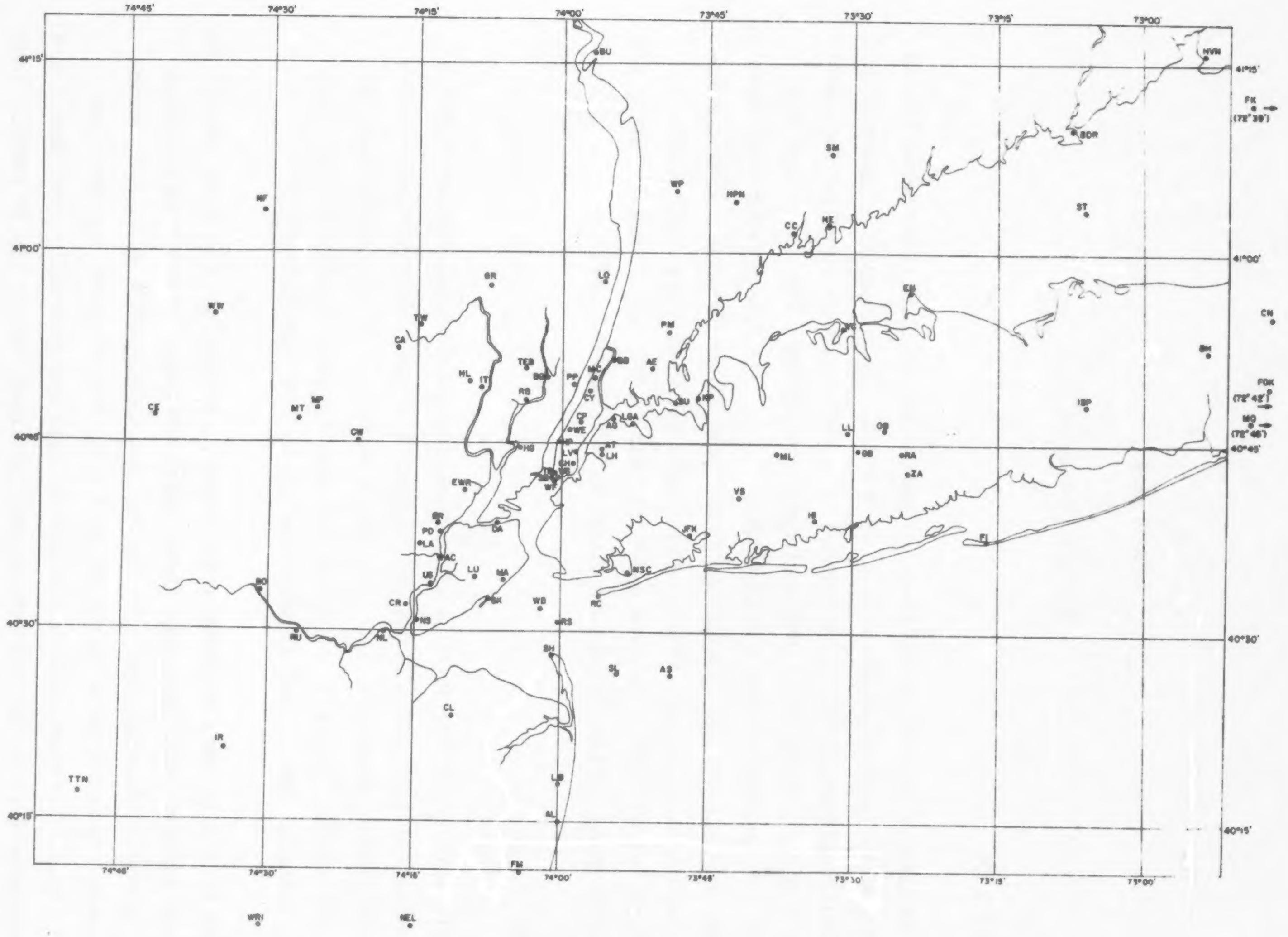
SAMPLING AREA

A mesoscale network of anemometers was established in and around NYC as part of the New York City Air Pollution Project. This network (Figure 10 and Table 24) consisted of 97 sites located in a rectangle centered on the west side of mid-town Manhattan. The rectangle was 200 km long in the E-W direction and 100 km long in the N-S direction. Data from the network were used to study mesoscale perturbations on synoptic scale flows (Scudder, 1965); mesoscale trajectories (Dryan, 1968); urban-rural wind velocity differences (Bornstein, et al. 1972, Johnson and Bornstein, 1974, and Johnson, 1975); and urban effects on frontal movement (Loose and Bornstein, 1975).

ANALYSIS

Data were collected from 14 airport stations (National Weather Service and Federal Aviation Administration), 4 military bases (Air Weather Service and Naval Weather Service), 10 Coast Guard bases, 15 utility companies, 14 industrial sites, 29 public agencies and institutions (Public Health, sanitation, schools, etc.), and 11 sites set up by New York University.

The wind data were averaged over 1 hour, centered on the hour, except for data from airport, military, and Coast Guard stations, which were standard hourly synoptic observations. During the shakedown period before T1, windspeeds were corrected to a height of 30.5 m by use of power law profiles. However, since the magnitude of the corrections was generally less than 1 $m \cdot s^{-1}$, the procedure was not carried out on data obtained during the 12 regular test periods.



74°45'
74°30'
74°15'
74°00'
73°45'
73°30'
73°15'
73°00'
41°15'
41°00'
40°45'
40°30'
40°15'
HVN
FK
(72°39')
BDR
SM
WP
HPN
NF
CC
NE
ST
GR
LO
EN
WW
TW
CA
PM
CN
TEB
ML
IT
BG
PP
MC
AE
BH
CE
MT
MP
RS
CY
SU
KP
ISP
FOK
(72°42')
CW
WE
AS
LGA
LL
OB
MO
(72°48')
HG
AT
LH
GB
RA
ML
EWR
ZA
VS
PD
DA
JFK
HI
LA
NAC
FI
LU
MA
NSC
BO
US
SK
WB
CR
NS
RC
RS
RU
NL
SH
AS
CL
IR
TTN
LB
AL
FM
WRI
NEL

Figure 10. Location of surface anemometer sites by abbreviations used in Table 24.

TABLE 24. ALPHABETICAL LISTING OF SURFACE ANEMOMETER SITES APPEARING IN FIGURE 10

Code Letters	Station Name	Lat. (D M S)	Long. (D M S)	Data Type	Obstructed Arc^{1}	Problems
AE	Albert Einstein Sch.	40 51 00	73 50 45	A	WNW	
AG	Astoria Generator	40 47 06	73 54 45	A		L
AL	Allenhurst	40 15	74 00	A		D
AS	Ambrose Light Ship	40 27 20	73 50 00	O^{2}		
BA	Bayonne	40 41	74 07	U		
BB	Bliss Bldg., NYU	40 51 40	73 54 45	B^{3}	NW	
BDR	Bridgeport Airport	41 10	73 07	W		
BG	Bergen Generator	40 50 25	74 01 40	B	NE	L,D
BO	Bound Brook	40 33 30	74 30 30	U		L
BR	Bayway Refinery	40 38 40	74 12 30	A	NW	S
BT	Yonkers	40 58	73 53	U^{4}		S
BU	Buchanan	41 16 10	73 57 00	A		L
CA	Caldwell Airport	40 52 35	74 16 55	O		
CC	Cos Cob	41 01 48	73 35 54	A		L
CE	Chester	40 48	74 42	A		L,F
CH	Christadora House	40 43 30	73 58 50	B		L
CL	Crawford Hill	40 23	74 11	B		F
CN	Grumman Aircraft	40 55	72 47	W		
CP	Central Park	40 46 45	73 58 10	Q	NW	L
CR	Perth Amboy	40 32 05	74 15 48	A		
CW	Commonwelth Water	40 15	74 21	U		
CY	City College of N.Y.	40 49 15	73 57	A		D
DA	Con. Edison	40 38 40	74 06 40	B		
EN	Eatons Neck	40 52 02	73 23 07	WQ		
ER	Execution Rocks	40 52 40	73 44 00	WQ		
EWR	Newark Airport	40 31 00	74 09 30	W		
FH	Fort Hamilton	40 36	74 01	U		
FI	Fire Island	40 37 05	73 15 06	WQ		
FK	Falkners Island	41 12 07	73 39 02	WQ		
FM	Fort Monmouth	40 11	74 04	B	E	
FOK	Suffolk	40 50	72 40	W		
FV	Fairview	40 49	74 00	U		L,F

(continued)

TABLE 24. (continued)

Code Letters	Station Name	Lat. (D M S)	Long. (D M S)	Data Type	Obstructed Arc[1]	Problems
GB	Bathpage	40 44	73 29	WQ		
GK	Great Kills	40 32 45	74 07 26	P		
GR	Glenrock School	40 57 28	74 07 29	B		
HE	Stamford	41 02 26	73 23 39	U	NW	D
HG	Hudson Generator	40 44 41	74 04 24	B	SW/ NW	
HI	Merrick	40 38 59	73 33 45	U		
HL	Hoffman Laroche	40 49 48	74 09 30	A		D
HP	Pier 68 Heliport	40 45 15	74 00 30	B	NE/ S	L
HPN	White Plains Airport	41 04	73 44	W		
HR	West Hempstead	40 42	73 39	O	WNW	
HVN	New Haven Airport	41 16	72 58	W		
IR	Plainsboro	40 20 47	74 34 10	B		
IS	Westwood	40 59	74 00 54	Q	NNW	
ISP	Islip Airport	40 43	73 06	W		
IT	Nutley	40 49 18	74 08 18	U		
JFK	JFK Intn'l. Airport	40 38 05	73 46 45	W		
KP	Kings Point Academy	40 48 50	74 45 55	B		
LA	Linden Airport	40 37	74 14	U		F
LB	Long Branch	40 18	74 00	U		
LGA	La Guardia Airport	40 46 50	73 52 35	W		
LGA	La Guardia Airport	40 46 50	73 52 35	Q		S,D
LH	Laural Hills	40 44 12	73 55 48	A	NW	D
LL	Long Is. Lighting	40 45 48	73 30 48	B		D
LO	Lamont Tower	40 57 30	73 55 25	A		D
LU	Latouratte	40 34 30	74 03 55	P		
LV	Lehigh Valley	40 44 30	73 58 20	B	SSW/ NNE	L,D
MA	Fort Miller	40 34 08	74 24 08	B		
MC	Medical Center	40 50 25	73 56 30	P		
ML	Mineola	40 44 10	73 30 00	B		D
MO	Moriches	04 47 02	72 45 00	WQ		

(continued)

TABLE 24. (continued)

Code Letters	Station Name	Lat. (D M S)	Long. (D M S)	Data Type	Obstructed Arc[1]	Problems
MP	Morristown Airport	40 47 50	74 25 05	U		
MT	Morristown	40 46 45	74 27 00	A	6	D
NEL	Lakehurst	40 10	74 15	W		
NL	Nation Lead	40 29 50	74 18 35	A		
NR	New Rochelle	40 54	73 47	U		
NS	Totenville	40 32	74 14	A		D
NSC	Floyd Bennett	40 35	73 53	W		
OB	Oyster Bay	40 46 15	73 28 40	B	6	
OC	Oceanside	40 37 10	73 38 21	U		D
PD	Phelps Dodge	40 38 05	74 12 10	B		S
PH	Pelham Manor	40 53 55	73 49 00	P		
PP	Palisades Park	40 49 45	73 53 30	P		
RA	Republic Aviation	40 44	73 25	U		D
RB	NYU Research No. 4	40 48 35	74 03 45	B		
RC	Rockaway	40 33 02	73 56 02	WQ		D
RP	Roselle Park	40 39	74 16	U		S
RU	Rutgers Univ.	40 30	74 27	B		L
SB	Sheraton Bldg.	40 42 15	74 01 00	Q		
SH	Sandy Hook	40 28 01	74 01 00	WQ		
SM	Stamford	41 08	73 32	Q		
ST	Stratford Shoals	40 03 04	73 06 01	WQ		
SU	Maritime College	40 48 20	73 47 42	B		D
TB	NY Telephone Co.	40 42 50	74 00 45	B		
TEB	Teterboro Airport	40 46	74 03 55	W		
TW	Totawe Wayne Airport	40 54 35	74 14 39	O		
US	U.S. Metals	40 35 55	74 13 15	B		L
VS	Memorial School	40 40 35	73 41 50	O		L
WE	West End	40 46 05	73 59 10	B	7	
WF	Whitehall Ferry	40 42	74 00 45	B	N/NE	
WP	Westchester	41 04 45	73 48 20	B		D
WRI	McGuire	40 00 40	74 36 40	W		
WS	Wall Street	40 42 15	74 00 30	B		
WW	West Wharton	40 55	74 36	A		S,D

(continued)

TABLE 24. (continued)

Code Letters	Station Name	Lat. (D M S)	Long. (D M S)	Data Type	Obstructed Arc[1]	Problems
YC	Yatch Club	40 54 10	73 30 45	B		
ZA	Zahn's Airport	40 42	73 24	W		

NOTES:

I. TYPE OF DATA

A - TWO ROLL BENDIX
B - ONE ROLL BENDIX
O - VISUALLY OBSERVED
P - FROM SECOND LEVEL OF PIBAL
Q - QUADRUPLE, TRIPLE, OR DOUBLE REGISTER
W - WBAN 10 OR SERVICE A
WQ - COAST GUARD CIRCUIT (QUADRUPLE REGISTER)
U - UNKNOWN

II. FOOTNOTES

1. IF TWO DIRECTIONS GIVEN, FIRST IS BEGINNING OF OBSTRUCTED ARC AND LAST IS ITS END, MOVING IN A CLOCKWISE SENSE.
2. WIND SPEED CONVERTED FROM BEAUFORT.
3. IF WIND RECORDER INOPERATIVE, PIBAL WINDS SOMETIMES USED.
4. WIND SPEEDS REPORTED EITHER AS 2.5 OR 7.5 MPH; DATA NOT USED.
5. USED ONLY WHEN RECORDER WAS INOPERATIVE.
6. ROOF AERODYNAMIC EFFECT.
7. ALL QUADRANTS.
8. 287 m ABOVE GROUND LEVEL.

III. PROBLEMS

D -- ORIENTATION PROBLEMS	L - LOCAL EFFECTS
F - TOO FAST	S - TOO SLOW

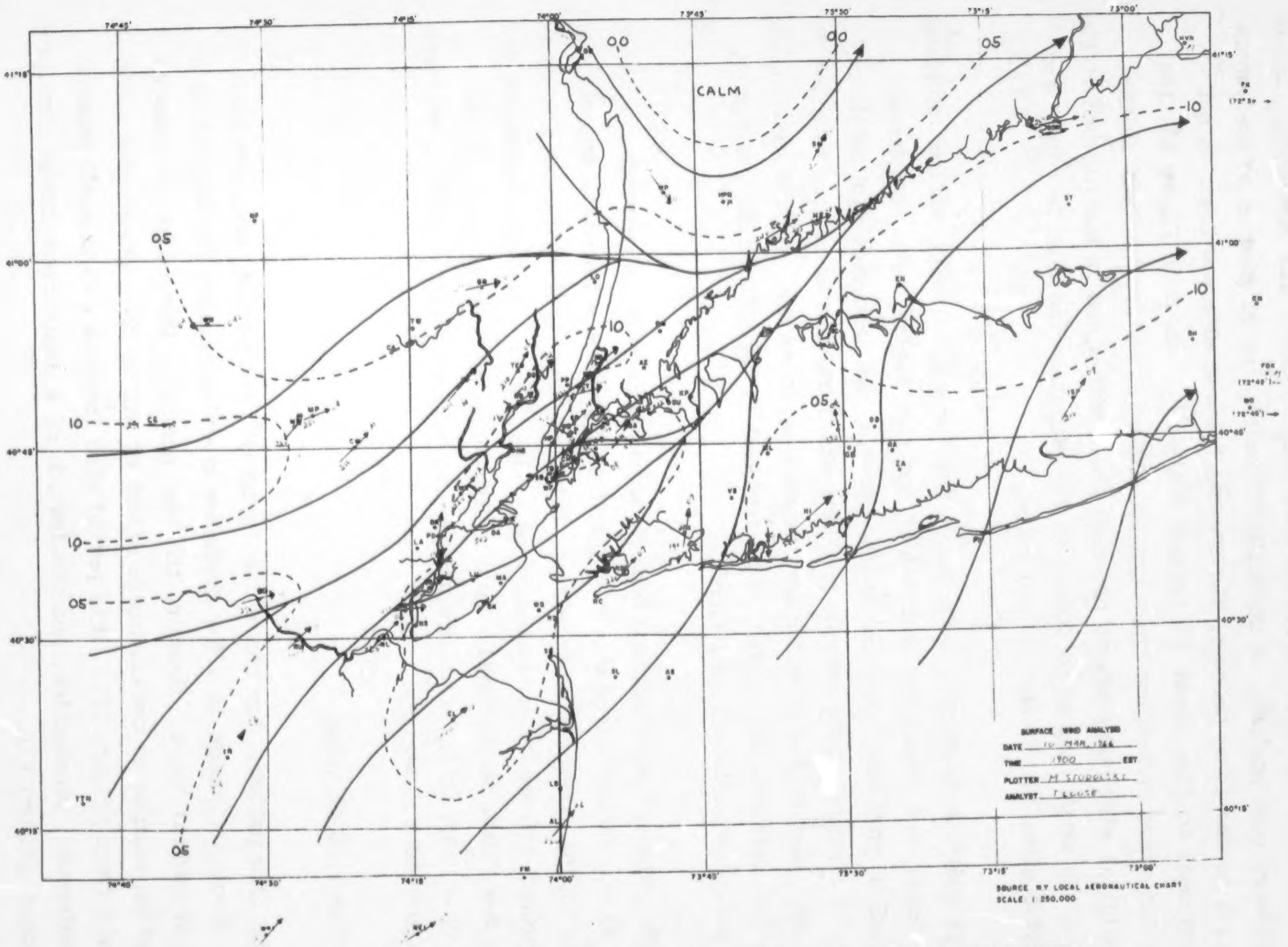
The hourly-average windspeed and direction data were plotted onto maps, and streamflow and isotach analyses were made for each hour during the days of the primary test periods. A streamflow line is here defined to be everywhere parallel to the flow; however, the spacing between adjacent lines is not proportional to flow speed. A typical analysis is shown in Figure 11; the solid lines are streamflow lines and the dashed lines are isotachs in mph. The original wind observations are also shown with speed in mph plotted at the head of the arrow (the arrow points in the direction the wind is going) and direction given at the back of the arrow.

In addition to missing data (about 25% for a given map), various problems were encountered during the analysis of the flow fields, e.g., instrument orientation problems, local channeling effects, and incorrect plotted directions. A summary of the various problems encountered at each site is given in Table 24. Most of the problems were transitory in nature, and the vast majority of the data was good enough to be included in the NYU and SJSU analyses, even under low windspeed conditions.

The primary considerations behind the analyses were to maintain a continuity of the patterns from map to map and to reproduce a realistic but simple pattern of the general mesoscale flow in the region. Continuity was achieved by viewing three maps simultaneously on a light table. Features appearing on only a few charts were viewed suspiciously. A major determination of the validity of such features was the number and quality of the reporting stations in the area of the feature.

SUMMARY OF FLOW PATTERNS

The flow patterns for two of the "primary" test periods are generally fairly smooth, although in a few instances the flow rotates 180 degrees in a period of several hours. However, the test period of March 1966 includes an interesting example of the mesoscale effect of NYC on the passage of a synoptic scale front (Figure 12). This period also includes a case study showing the development, penetration, and dissipation of a complex sea breeze circulation system (Figure 13).


CALM
00
00
05
05
05
05
05
10
10
10
10
10
74°45'
74°30'
74°15'
74°00'
73°45'
73°30'
73°15'
73°00'
74°40'
41°15'
41°00'
40°45'
40°30'
40°15'

SURFACE WIND ANALYSIS
DATE 10 MAR. 1966
TIME 1900 EST
PLOTTER M. STUDOLSKI
ANALYST T. LOOSE

SOURCE N.Y. LOCAL AERONAUTICAL CHART
SCALE 1:250,000

Figure 11. Streamflow and isotach (in mph) analyses for 1900 EST on March 10, 1966.

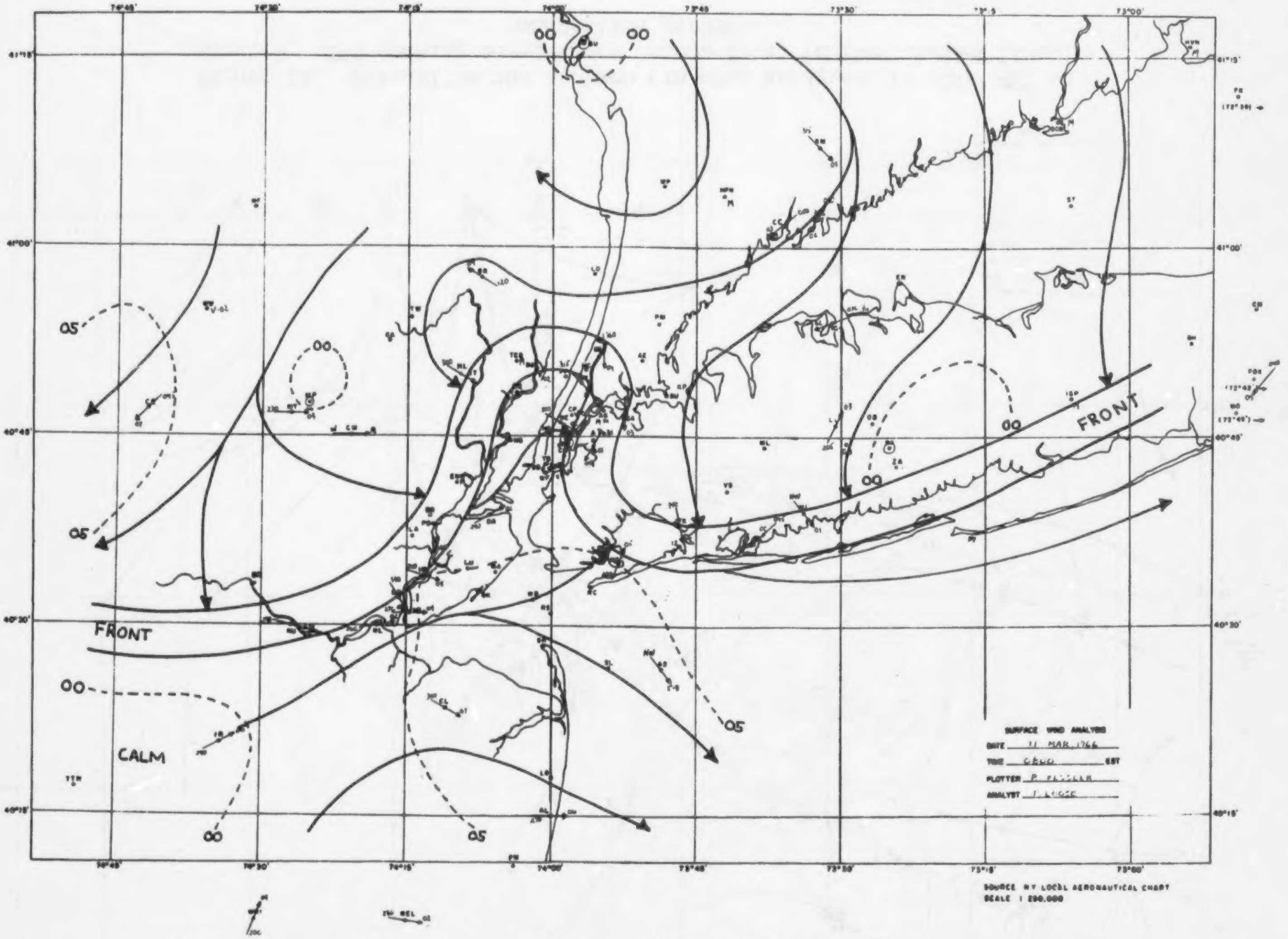

74°45'
74°30'
74°15'
74°00'
73°45'
73°30'
73°15'
73°00'
41°15'
41°00'
40°45'
40°30'
40°15'
FRONT
FRONT
CALM
00
05
SURFACE WIND ANALYSIS
DATE 11 MAR 1966
TIME 0800 EST
PLOTTER
ANALYST
SOURCE NY LOCAL AERONAUTICAL CHART
SCALE 1:250,000

Figure 12. Streamflow and isotach (in mph) analyses for 0800 EST on March 11, 1966 showing frictional retardation of synoptic front over NYC.

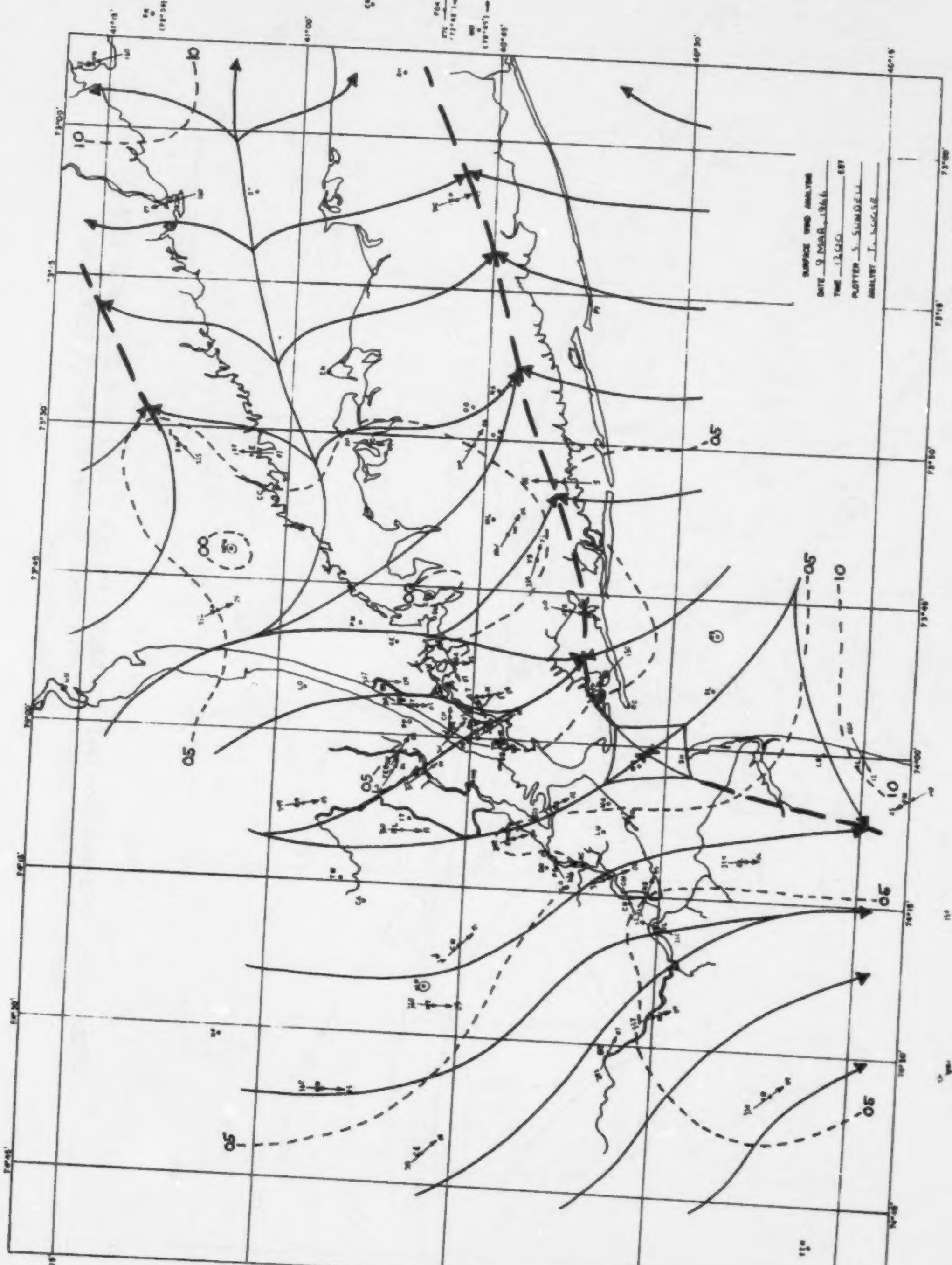

SURFACE WIND ANALYSIS
DATE 9 MAR 1966
TIME 1200 EST
PLOTTER S. SUNDELL
SOURCE N Y LOCAL AERONAUTICAL CHART
10
05
10
05
05
10
05
05

Figure 13. Streamflow and isotach (in mph) analyses for 1200 EST on March 9, 1966 showing complex sea breeze front (darker dashed lines) penetration pattern.

All of the hourly maps from the 11 days comprising the three primary test periods are on the microfilm on file at NTIS.

SECTION 5

UPPER LEVEL WIND DATA

During the Project, upper level wind data in the lowest kilometer of the atmosphere were obtained by the following methods: (1) a single theodolite tracking a single free-rising pilot balloon; (2) two theodolites tracking a single free-rising pilot balloon; (3) four theodolites tracking two free-rising pilot balloons; and (4) radar-tracked radiosonde launches at the U.S. Weather Service site at John F. Kennedy (JFK) Airport.

When four theodolites were used in an experiment, two of them were used to track each balloon. The two balloons were released from sites separated by about 1 mile and were tracked so that simultaneous readings were taken of each balloon by its two tracking theodolites. Results were used to estimate the time rate of change of the correlation coefficients obtained from the two velocity data sets.

The above pibal and rawinsonde data have been analyzed at SJSU by the following series of computer programs: (1) DATA CHK, which checks punched cards containing the original pibal and JFK observations for various keypunching and filing errors; (2) DATA, which transfers the original observations from the cards to a "BCD" formatted, unblocked, 7-track, 800-bpi computer input data tape and then prints the data; (3) DUMP, which lists any part of the input data tape; (4) EDIT, which can correct any errors found in the input data; (5) WIND, which computes and prints wind velocities for particular pibal runs using the data on the input data tape; (6) WIND2, which computes wind velocities from the input data tape for particular runs and then puts the output onto a new "BCD" formatted, unblocked, 7-track, 800-bpi computer tape; and (7) EPATAP, which reads the new tape generated by WIND2 and then lists the wind velocities for particular pibal runs.

The tape generated by the WIND2 computer program,and the EPATAP program necessary to read that tape and to list the velocities from particular pibal runs, are available at NTIS.

Program DATA assigns a run number to each pibal launch chronologically and separates the launches into various files according to launch site (shown in Figure 14) and date. The list of files so created is given in Table 25. Those runs from the three primary test periods, and thus on the NTIS tape, are indicated by asterisks preceding their file numbers.

The input cards needed for program EPATAP are shown in Figure 15. Each card gives the starting and terminating run numbers of a group of pibal runs to be read from the NTIS tape and printed. The starting and terminating run numbers must end in the fifth and tenth columns, respectively. Any number of groups of pibal runs can be read from the tape during a single computer run. A blank card stops the run selection process and terminates the computer run.

The listing of the output from a typical pibal launch is shown in Table 26. The top line gives the site location. The second line lists the run number, the date of the launch, the time of the launch in EST, and the height of the launch site in meters above mean sea level (MSL) and above ground level (AGL). The actual tabulated data includes the following input data at various levels: (1) the azimuth angle in degrees east of true north; (2) the elevation angle in degrees above the horizontal; and (3) the height of the balloon above mean sea level in meters at the midpoint of the layer through which it passed during the period between the latest (to that time) two sets of actually obtained (excluding missed sets) azimuth and elevation angles.

A constant rate of ascent of 150 $m \cdot min^{-1}$ has been assumed to obtain the height of the balloon at any given moment above the local ground level. Most of the theodolite azimuth and elevation readings were taken at 15-s intervals, although on occasion 30- or 60-s intervals were used. The 15-s interval yielded computed velocities at 37.5-m intervals, except in the case of missing levels, while a knowledge of the height of the launch site above mean sea level allowed for the data to be listed at heights above mean sea level.

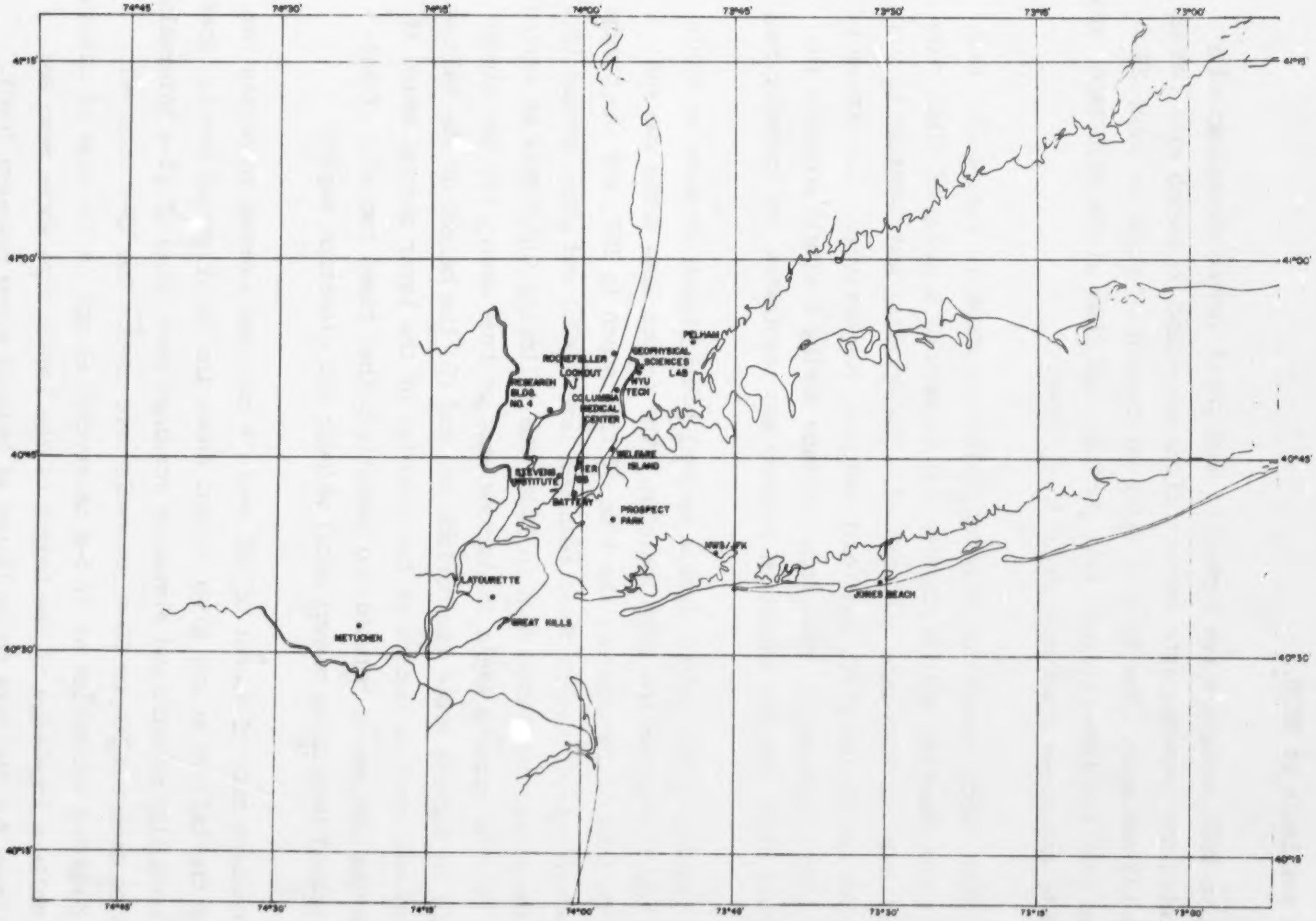

74°45'
74°30'
74°15'
74°00'
73°45'
73°30'
73°15'
73°00'
41°15'
41°00'
40°45'
40°30'
40°15'
PELHAM
GEOPHYSICAL SCIENCES LAB
ROCKEFELLER LOOKOUT
RESEARCH BLDG. NO. 4
NYU TECH
COLUMBIA MEDICAL CENTER
WELFARE ISLAND
STEVENS INSTITUTE
PIER
BATTERY
PROSPECT PARK
NWS/JFK
JONES BEACH
LATOURETTE
GREAT KILLS
METUCHEN

Figure 14. Location of pibal launch sites and NWS radiosonde site at JFK Airport listed in Table 25.

TABLE 25. LIST OF FILES GENERATED BY PROGRAM DATA

See Table 1 for dates included in the various test periods.

FILE NO.	STATION	PERIOD	RUN NOS.
1	G.S.L.	I-7/8	1001-1002
2	"	I-8/9	1003-1007
3	Jones Beach	PT-1	2001-2002
4	Metuchen	T-9	3001-3023
*5	"	T-12	3024-3064
6	Prospect Park	PT-1	4001-4003
7	Rockefeller Lookout	PT-1	5001-5010
8	Great Kills	PT-1	6001-6123
9	" "	T-7	6124-6145
10	" "	T-8	6146-6147
11	" "	T-9	6148-6149
12	Kennedy Airport	PT-1	7001-7165
13	" "	T-2	7166-7180
14	" "	T-4	7181-7196
15	" "	T-5	7197-7210
*16	" "	T-6	7211-7228
17	" "	T-7	7229-7246
18	" "	T-8	7247-7258
19	" "	T-9	7259-7261
*20	" "	T-10	7262-7277
*21	" "	T-12	7278-7288
22	Latourette	PT-1	8001-8138
23	NYU Tech.	PT-1	9001-9104
24	" "	T-1	9105-9148
25	" "	T-2	9149-9198
26	" "	T-4	9199-9264
27	" "	T-5	9267-9310
*28	" "	T-6	9311-9404
29	" "	T-7	9405-9488
30	" "	T-8	9489-9521
31	" "	T-9	9522-9543
*32	" "	T-10	9544-9606
*33	" "	T-12	9607-9668
34	Pelham Manor	PT-1	10001-10166
35	" "	T-7	10167-10195
36	" "	T-8	10196-10204
37	" "	T-9	10205-10213
*38	" "	T-10	10214-10247
*39	" "	T-12	10248-10286
40	Research Bldg. #4	PT-1	11001-11142
41	" " "	T-4	11143-11188
42	" " "	T-5	11189-11247

(continued)

TABLE 25 (continued)

FILE NO.	STATION	PERIOD	RUN NOS.
*43	Research Bldg. #4	T-6	11248-11340
44	" " "	T-7	11341-11432
45	Welfare Island	T-8	12001-12030
46	" "	I-8/9	12031-12045
47	" "	T-9	12046-12064
*48	" "	T-10	12065-12125
*49	" "	T-12	12126-12171

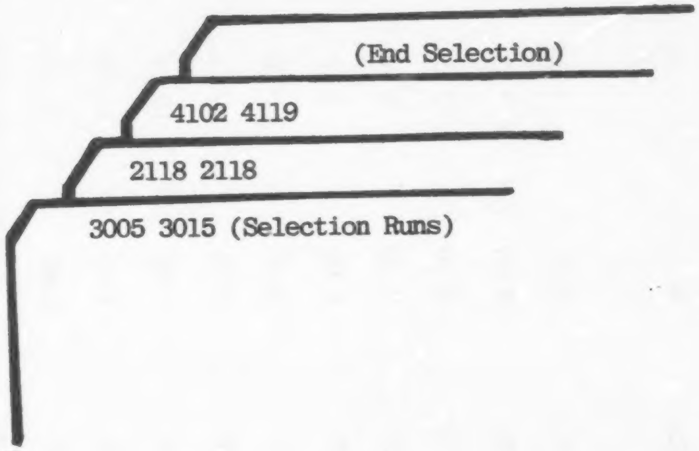

(End Selection)
4102 4119
2118 2118
3005 3015 (Selection Runs)

Figure 15. Input data deck for program EPATAP.

TABLE 26. LISTING OF OUTPUT FROM PROGRAM EPATAP FOR A TYPICAL PIBAL LAUNCH

```
                                     STATION NAME       RESEARCH BLDG. NO. 4
RUN NUMBER 11345   DATE  5/ 3/66   TIME 1320     EST   STATION HEIGHT  10 M(MSL)   O M(AGL)
   AZIMUTH        ELEVATION   HEIGHT      U               V          DIRECTION     SPEED
   (DEG.)          (DEG.)      (M)      (MPS)           (MPS)          (DEG)       (MPS)

 1   28.78          15.64      28.75     4.30            7,83         208.78        8.93
 2   MISSING DATA
 3   32.78          16.04      85.00     4.91            7.05         214.86        8.59
 4   32.48          16.11     141.25     4.47            7.27         211.56        8.54
 5   33.50          15.79     178.75     5.80            7.65         217.18        9.61
 6   34.04          15.29     216.25     6.32            8.61         216.28       10.67
 7   33.67          14.95     253.75     5.62            9.08         211.77       10.68
 8   33.52          14.62     291.25     6.00            9.38         212.64       11.13
 9   33.60          14.30     328.75     6.51            9.60         214.13       11.60
10   33.66          13.84     366.25     7.40           10.94         214.06       13.21
11   33.67          13.38     403.75     7.85           11.75         213.74       14.14
12   34.02          13.72     441.25     4.65            5.63         219.57        7.30
   AVERAGE DIRECTION = 214.02 DEGREES          AVERAGE WINDSPEED = 10.25 m·S⁻¹
```

From the input azimuth angle, elevation angle, and height values, the following are computed at the heights defined just above: (1) the u or west to east component of the wind in meters per second (mps); (2) the v or south to north component of the wind in mps; (3) the horizontal wind direction in degrees east of true north; and (4) the total horizontal windspeed in mps. Below these tabulated values are the averaged wind direction in degrees east of north and the averaged total horizontal windspeed in mps for the entire launch. The averaged total horizontal windspeed was obtained by averaging the speeds at all levels, instead of by averaging computed u and v components at each level, as is done to compute the average wind direction.

The radiosonde data obtained by the U.S. Weather Service at JFK Airport and the output from the EPATAP program for a typical JFK launch is identical to that in Table 26. The main difference between the JFK launches and the pibal launches is the six "known heights" that the Weather Service supplies for each JFK launch. Thus, there is no need to assume a constant rate of ascent. A smoothing routine is used with the JFK data so that three readings, taken at 6-s intervals, are used to compute a single wind over a layer of about 90 m.

SECTION 6

SURFACE SO_2 OBSERVATIONS

SAMPLING AREA

The surface SO_2 observational network consisted of 33 fixed sites, two instrumented automobiles, and one instrumented truck. The geographic distribution of the fixed sites, shown in Figure 16, was as follows: 10 in Manhattan; 6 in Brooklyn; 8 in Queens; 6 in The Bronx; 1 in Richmond; and 2 in New Jersey. Generally 70 to 80% of the fixed stations were in operation at any given time. The readings from each instrument were averaged for 1-hour periods, centered on the half-hour.

In addition to the data measured at the fixed station network, observations were also obtained from instrumented cars and trucks driven over the specified routes shown in Figure 17. At each of the numbered sites shown in the figure and listed in Table 27, the vehicles were stopped and concentrations were recorded over periods of 2 to 3 minutes. Depending on the wind direction, the instrumented cars followed one of the routes listed in Table 28.

INSTRUMENTATION

For analysis purposes, the 33 fixed sites were placed into three categories, as shown in Table 29, according to the group maintaining the particular monitoring device. The eight stations in Group I were instrumented with electroconductivity devices manufactured by the Davis Company. These devices were installed and maintained by Project members from NYU. The calibration of these instruments included compensation for interference associated with atmospheric CO_2, and is discussed in the following subsection.

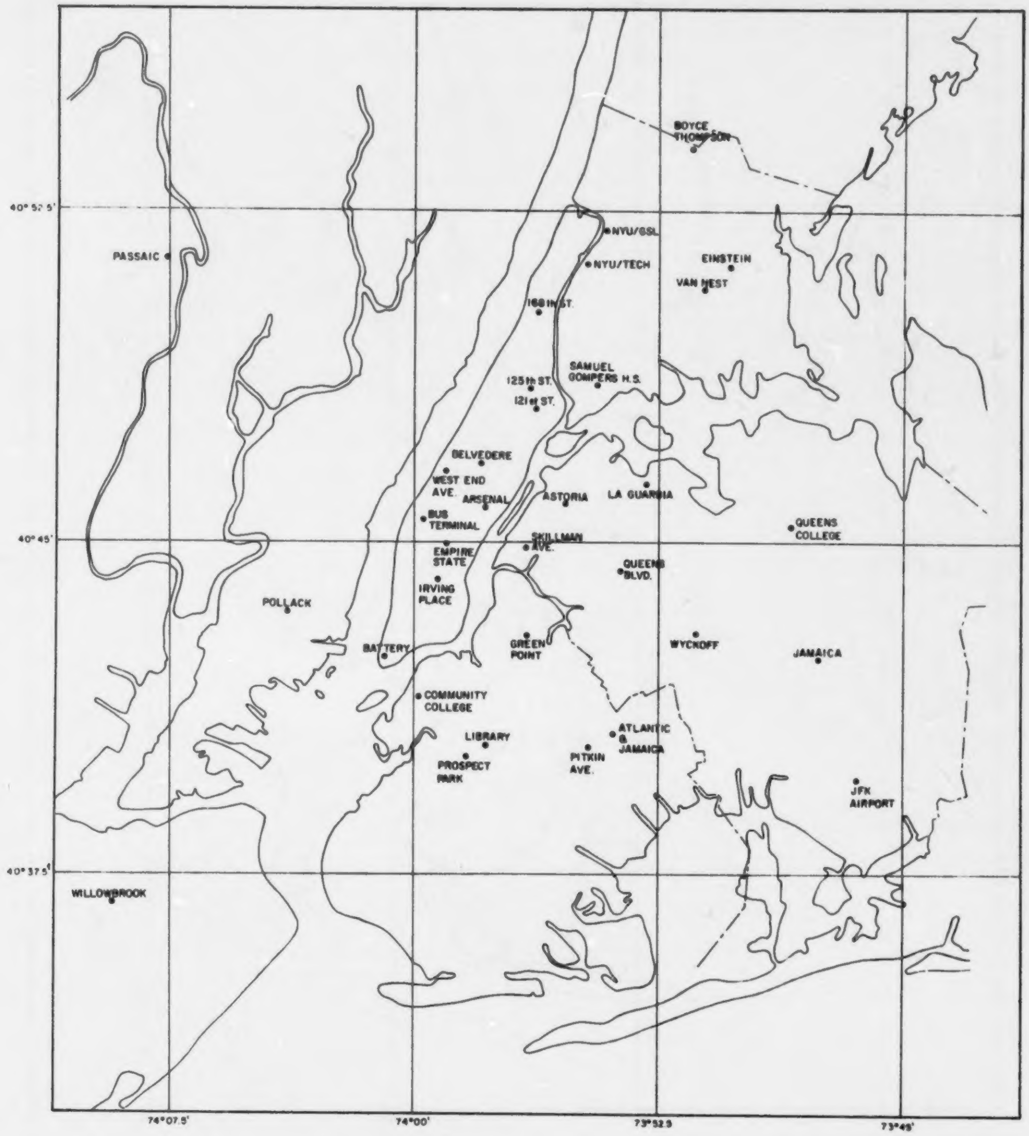

BOYCE THOMPSON
40° 52.5'
NYU/GSL
PASSAIC
NYU/TECH
EINSTEIN
VAN NEST
168th ST.
SAMUEL GOMPERS H.S.
125th ST.
121st ST.
BELVEDERE
WEST END AVE.
ARSENAL
ASTORIA
LA GUARDIA
BUS TERMINAL
QUEENS COLLEGE
40° 45'
SKILLMAN AVE.
EMPIRE STATE
QUEENS BLVD.
IRVING PLACE
POLLACK
WYCKOFF
BATTERY
GREEN POINT
JAMAICA
COMMUNITY COLLEGE
ATLANTIC & JAMAICA
LIBRARY
PITKIN AVE.
PROSPECT PARK
JFK AIRPORT
40° 37.5'
WILLOWBROOK
74°07.5'
74°00'
73°52.5
73°45'

Figure 16. Location of fixed surface SO_2 monitoring sites.

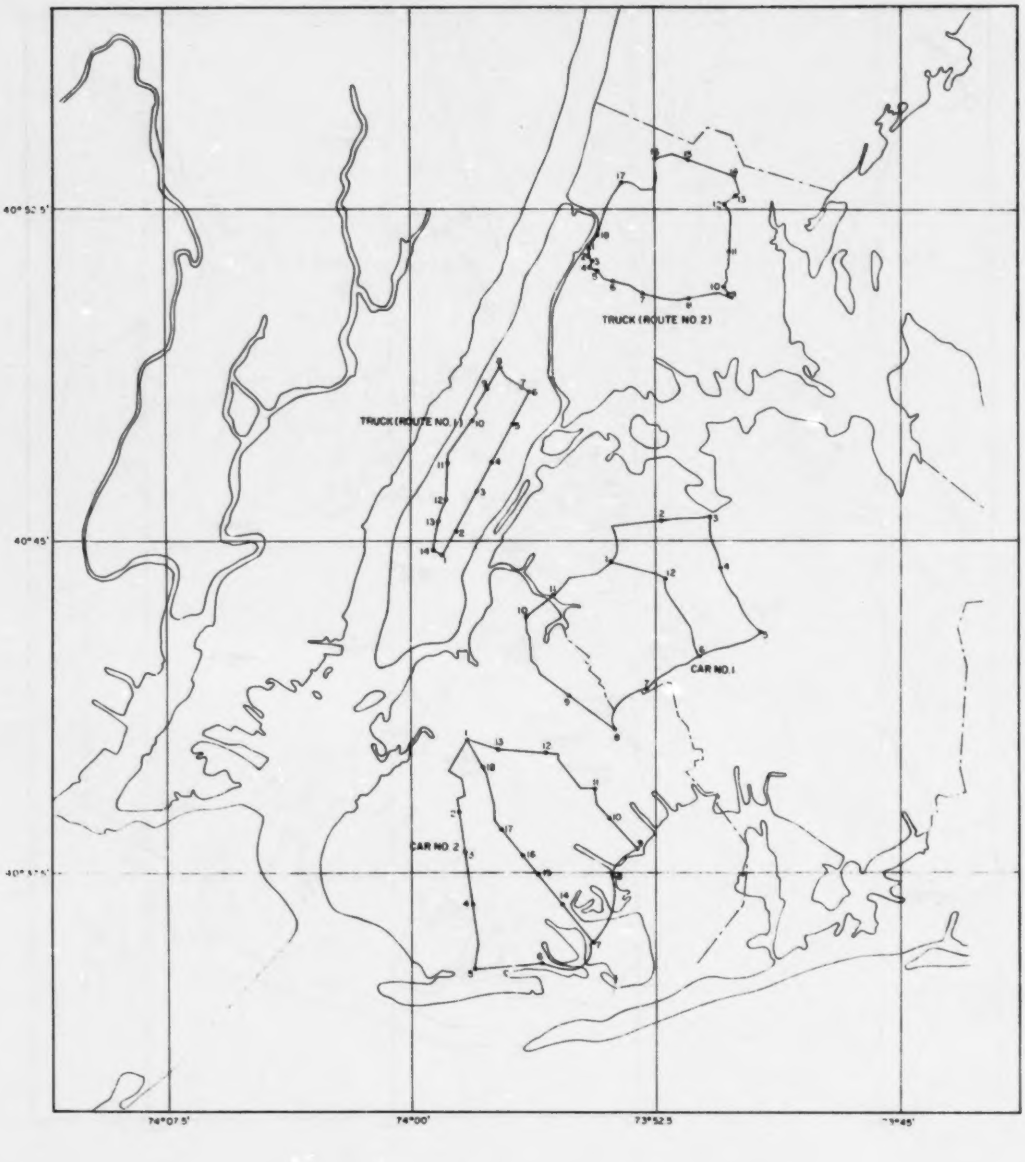

40°52.5'
40°45'
40°37.5'
74°07.5'
74°00'
73°52.5
73°45'
TRUCK (ROUTE NO. 2)
TRUCK (ROUTE NO. 1)
CAR NO. 1
CAR NO. 2

Figure 17. Location of stops made by the mobile SO_2 monitors, as listed in Table 27.

TABLE 27. POSSIBLE STOPS IN MOBILE SURFACE SO_2 SAMPLING PROGRAM

A. Car No. 1

Stop No.	Site
1.	Brooklyn Queens Exp. & Queens Blvd.
2.	Northern Blvd. & Junction Blvd.
3.	" " & Grand Central Pkwy.
4.	Grand Central Pkwy. & Long Island Exp.
5.	" " " & Interborough Pkwy.
6.	Interborough Pkwy. & Woodhaven Blvd.
7.	" " & Cypress Ave.
8.	" " & Bushwick Ave.
9.	Bushwick Ave. & Gates Ave.
10.	" " & Brooklyn Queens Exp.
11.	Brooklyn Queens Exp. at Kosciuszko Bridge.
12.	Queens Blvd. & Woodhaven Blvd.

(continued)

TABLE 27 (continued)

B. Car No. 2

Stop No.	Site
1.	Eastern Pkwy. at Brooklyn Public Library.
2.	Ocean Pkwy. & Church Ave.
3.	" " & Foster Ave.
4.	" " & Ave. P.
5.	" " & Shore Pkwy. (Belt Pkwy.)
6.	Shore Pkwy. (Belt Pkwy.) & Knapp St.
7.	" " & Flatbush Ave.
8.	" " & Bridge over Paerdegat Basin.
9.	" " & Rockaway Pkwy.
10.	Rockaway Pkwy. & Flatlands Ave.
11.	" " & Linden Blvd.
12.	Eastern Pkwy. & Utica Ave.
13.	" " & Bedford Ave.
14.	Flatbush Ave. & Ave. P.
15.	" " & Flatlands Ave.
16.	" " & Ave. I.
17.	" " & Foster Ave.
18.	" " & Empire Blvd.

(continued)

TABLE 27 (continued)

C. Truck (Route No. 1)

Stop No.	Site
1.	Park Ave. & 28 St.
2.	" " & 42 St.
3.	" " & 65 St.
4.	" " & 85 St.
5.	" " & 105 St.
6.	" " & 125 St.
7.	125 St. & Lenox Ave.
8.	" " & Broadway.
9.	Broadway & 116 St.
10.	" & 96 St.
11.	" & 72 St.
12.	" & 55 St.
13.	" & 42 St.
14.	" & 28 St.

(continued)

TABLE 27 (continued)

D. Truck (Route No. 2)

Stop No.	Site
1.	Sedgwick Ave. at GSL.
2.	" " at NYU Hall of Fame.
3.	" " & Tremont Ave.
4.	W. Tremont Ave. & University Ave.
5.	" " & Jerome Ave.
6.	E. Tremont Ave. & Webster Ave.
7.	" " & Southern Blvd.
8.	" " & White Plains Rd.
9.	" " & Hutchinson River Pkwy.
10.	Eastchester Rd. & Williams Bridge Rd.
11.	" " & Pelham Pkwy.
12.	" " & Boston Rd.
13.	Boston Rd. & Provost Ave.
14.	E. 233 St. & Baychester Ave.
15.	" " & Bronx River Pkwy.
16.	" " & Jerome Ave.
17.	Sedgwick Ave. & Gun Hill Rd.
18.	" " & W. 197 St.

TABLE 28. ROUTES FOLLOWED BY INSTRUMENTED AUTOMOBILES

Site numbers listed in Table 27.

A. Car No. 1

Route	Site Numbers
A	1-11
B	1, 12, 7-11

B. Car No. 2

Route	Site Numbers
A	1-13
B	1-7, 14-18
C	1, 18-14, 7-13

TABLE 29. SITES IN FIXED SO_2 MONITORING NETWORK

GROUP I. (NYU/DAVIS)

	Site	Longitude (Deg.	Min.	Sec.)	Latitude (Deg.	Min.	Sec.)
1.	Passaic	74	07	35	40	51	26
2.	Pollack	74	03	54	40	43	28
3.	Central Park (Belvedere)	73	57	58	40	46	47
4.	Prospect Park	73	58	24	40	40	10
5.	JFK Airport	73	46	24	40	39	38
6.	Einstein	73	50	20	40	51	15
7.	NYU/GSL	73	54	05	40	52	01
8.	Library	73	57	51	40	40	22

GROUP II. (CONSOLIDATED EDISON/DAVIS)

	Site	Longitude (Deg.	Min.	Sec.)	Latitude (Deg.	Min.	Sec.)
1.	Empire State	73	59	02	40	45	00
2.	Irving Place	73	59	18	40	44	10
3.	Queens Blvd.	73	53	40	40	44	20
4.	Atlantic & Jamaica	73	53	53	40	40	39
5.	Pitkin Ave.	73	54	39	40	40	22
6.	West End Ave.	73	59	02	40	46	37
7.	125th St.	73	56	27	40	48	28
8.	Van Nest	73	51	08	40	50	43
9.	Queens College	73	48	26	40	45	20
10.	Jamaica	73	47	35	40	42	22

(continued)

TABLE 29 (continued)

GROUP III. (NYC)

	Site	Longitude (Deg.	Min.	Sec.)	Latitude (Deg.	Min.	Sec.)
A.	Davis						
	1. 121st St.	73	56	20	40	47	59
B.	Wet Chemistry						
	1. Willowbrook	74	09	15	40	36	50
	2. Battery	74	00	53	40	42	24
	3. Community College	73	59	52	40	41	30
	4. Green Point	73	56	31	40	42	52
	5. Skillman Ave.	73	56	35	40	44	52
	6. Bus Terminal	73	59	43	40	45	31
	7. Arsenal	73	57	50	40	45	46
	8. Astoria	73	55	22	40	45	53
	9. La Guardia	73	52	51	40	46	19
	10. Samuel Gompers H.S.	73	54	24	40	48	33
	11. 168th St.	73	56	10	40	50	12
	12. NYU/TECH	73	54	43	40	51	19
	13. Wyckoff	73	51	21	40	42	55
	14. Boyce Thompson	73	51	32	40	53	55

The 10 stations in Group II were also equipped with electroconductivity instruments from the Davis Company. However, these instruments were operated by the Consolidated Edison Company of New York, and some of the data concerning the magnitude of the proper CO_2 correction is questionable. The remaining stations (Group III) were operated by NYC. At all but one of the Group III sites, SO_2 concentrations were determined by use of the West-Gaeke wet chemical method and the data were not cross-checked against Davis observations. The remaining station in this group was equipped with a Davis electroconductivity device.

CALIBRATION PROCEDURES

At the beginning of the Project, six Davis electroconductivity instruments were purchased for continuous analysis and recording of ambient SO_2 concentrations in the range 0-5 ppm. (The instruments were identified as 64-336, 64-337, 64-338, 64-339, 64-340 and truck Davis, but the prefix 64, indicating the year of manufacture, was later dropped for convenience.) These instruments were a modified version of a previous Davis instrument that had been designed to measure high SO_2 concentrations in stacks. In adapting it for use with low concentrations in ambient air, the manufacturer had not had sufficient experience to guard against the instabilities and interferences that accompany such measurements.

When the instruments were put into operation at the NYU offices at Sedgwick Avenue, attempts were made to check instrument readouts against SO_2 concentrations measured by the West-Gaeke and Wilson wet chemical methods. Little success resulted in the very low concentration range. The observations indicated that the Davis instruments were experiencing interference from CO_2. Thus a gas dilution bench, using premixes of both SO_2 in nitrogen (N_2) and CO_2 in N_2 combined with dry air to produce gas mixtures of known SO_2 and CO_2 concentrations, was constructed in order to obtain calibration curves for each Davis instrument.

While instruments number 336-340 were being studied during the summer of 1965, Sign-X Corporation of Essex, Connecticut was developing a miniaturized

Davis instrument for an instrumented helicopter. It was calibrated in September 1965 using the same system described above. Concurrently with development of the calibration bench, arrangements were made to place the five Davis instruments at fixed installations in the field.

It was during this period that a solution to the problem of identifying the CO_2 concentration in a field sample of air was found. The solution is based on the high solubility of SO_2 and low solubility of CO_2 in water. If a field sample is bubbled through an impinger containing de-ionized water, all of the SO_2 and little of the CO_2 will be trapped in the water. The effluent gas leaving the impinger will contain essentially the same CO_2 concentration as the original, but no SO_2. Therefore the Davis response to the scrubbed effluent should be the same as its response to a mixture of CO_2 and dry air, except for small changes due to differences between the humidities of the impinger effluent and the dry sample.

Based on the arguments presented above, new calibration curves were prepared for each of the Davises (see Figure 18 for an example) as follows: (1) at a given SO_2 concentration, the scale deflection associated with CO_2 concentrations of 0, 200, 400, 600, 800, or 1000 ppm were determined; (2) the above step was repeated for SO_2 concentrations of 0, 0.2, 0.4, 0.6, 0.8, and 1.0 ppm; (3) the curves shown on the right-hand side of Figure 18 were constructed; and (4) the curves from the right-hand side of the figure were used to construct the smoothed curves on the left-hand side of the figure.

The CO_2 content of a sample can be identified by plotting the Davis reading (ordinate) for the scrubbed sample on a calibration curve (on the left-hand side of the figure) at an SO_2 concentration (abscissa) of zero. A calibration curve for that particular sample can then be interpolated between the nearest curves of the family of curves on the sheet. The unscrubbed Davis reading for the same sample, used with the interpolated curve, then yields the sample SO_2 concentration. It was found that the easiest way to obtain the actual SO_2 values was to convert the calibration curves of Figure 18 to tabulated values by use of Equation (12).

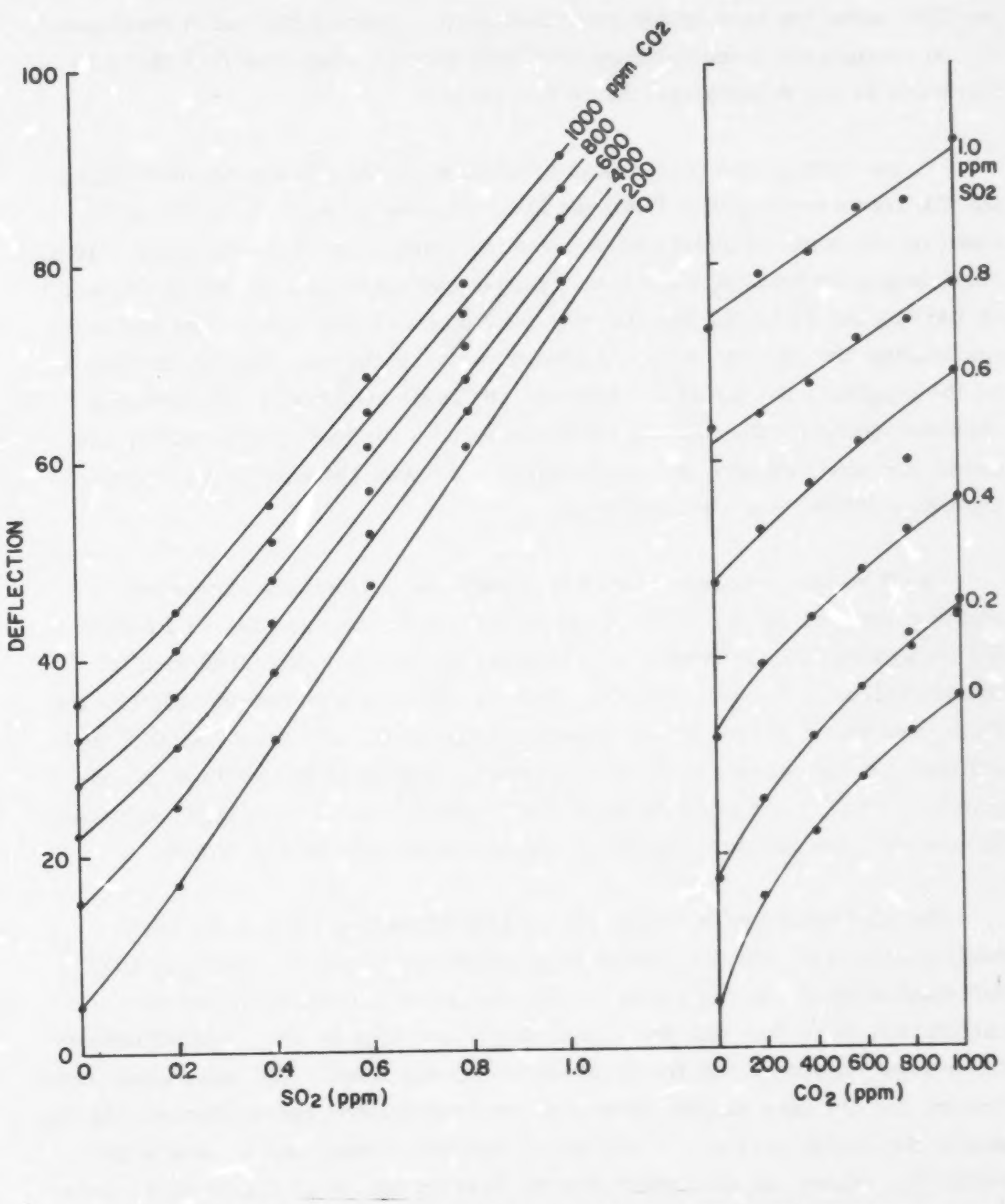


Figure 18. Calibration curves for a particular Davis SO_2 monitoring instrument. See text for explanation of how to use curves.

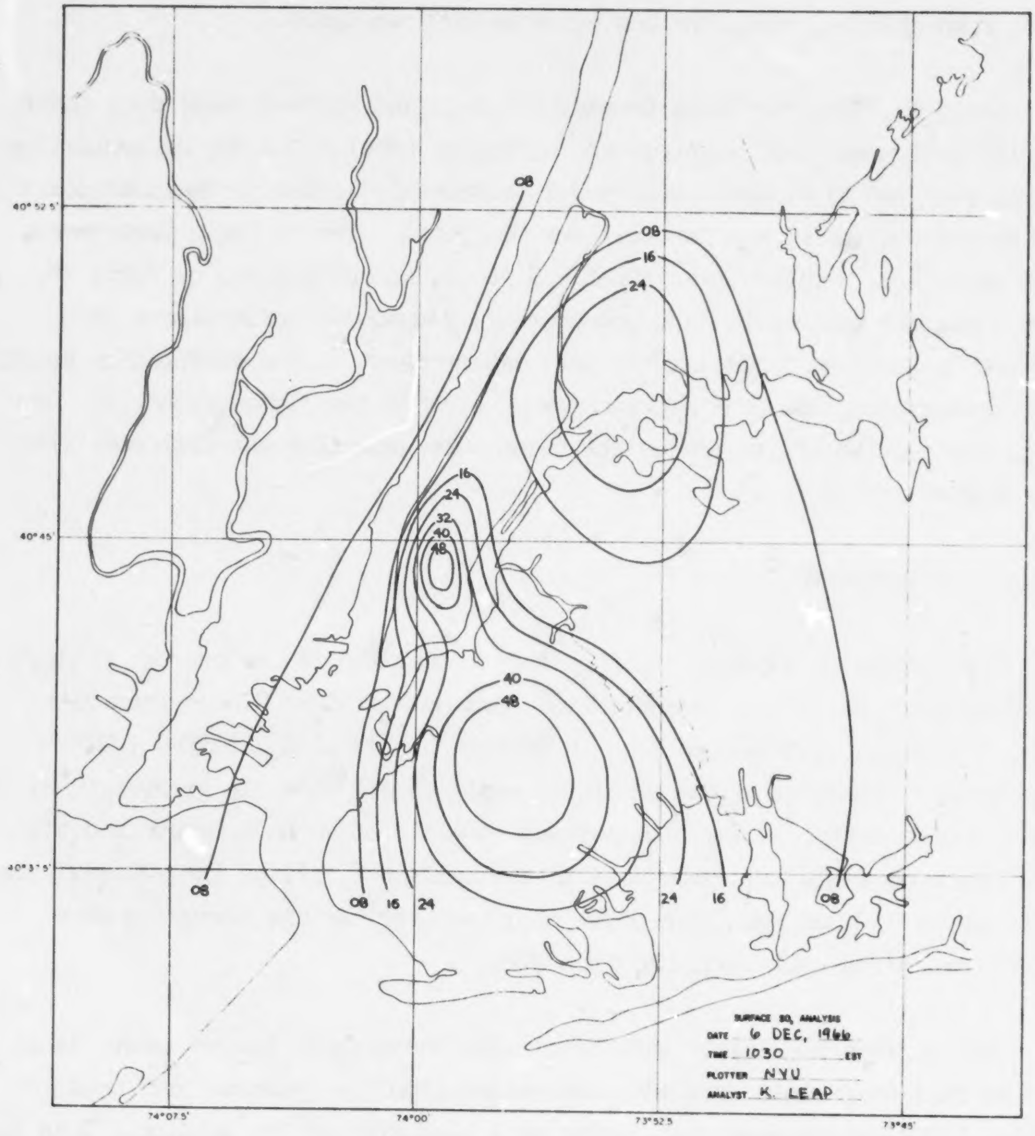
Sometime prior to March 15, 1966, Sign-X was commissioned to build two miniaturized Davis instruments for mobile traverses by car. These two units, identified as Car Davis 1 and Car Davis 2, were calibrated on March 15 and 17, 1966, respectively, using the new calibration procedures.

Early in 1966, the Davis Company produced an improved version of their bubbler instrument that incorporated a cycling bubbler for CO_2 determination and an improved electronic circuit for (supposedly) reducing the nonlinearity of the calibration curves in the lower SO_2 range. Two of these instruments were purchased, designated as #66-2 and #66-3, and calibrated on April 26, 1966 using the new calibration procedures. Subsequent calibrations were carried out several times after slight improvements to the calibration bench, e.g., standardization of the pressures of each of the flowmeter balls. However, the results of the new calibrations were generally not different from those shown in Figure 18.

ANALYSIS PROCEDURES

For the three "primary" test periods reanalyzed in the present study, isopleth analyses of SO_2 concentration were completed at 2-hour intervals using the averaged data described in Section 6 (SAMPLING AREA and INSTRUMENTATION). Examples of the resulting analyses are shown in Figures 19-21, in which mobile data from the time periods one-half of an hour before and after the indicated times have been used in the analyses. All of the 132 analyses from the 11 days of the three reanalyzed test periods are currently on a single microfilm roll available from NTIS.

The surface SO_2 charts were originally analyzed at 2-hour intervals at NYU so that they would coincide with output from the Gaussian puff model of Shieh (1969), which used that period as a time step of integration. This time scale coincides with the space scale defined by the average spacing between the sites in the surface SO_2 network, and thus little information is lost during the 2 hours between successive maps.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74°00'
73°52.5'
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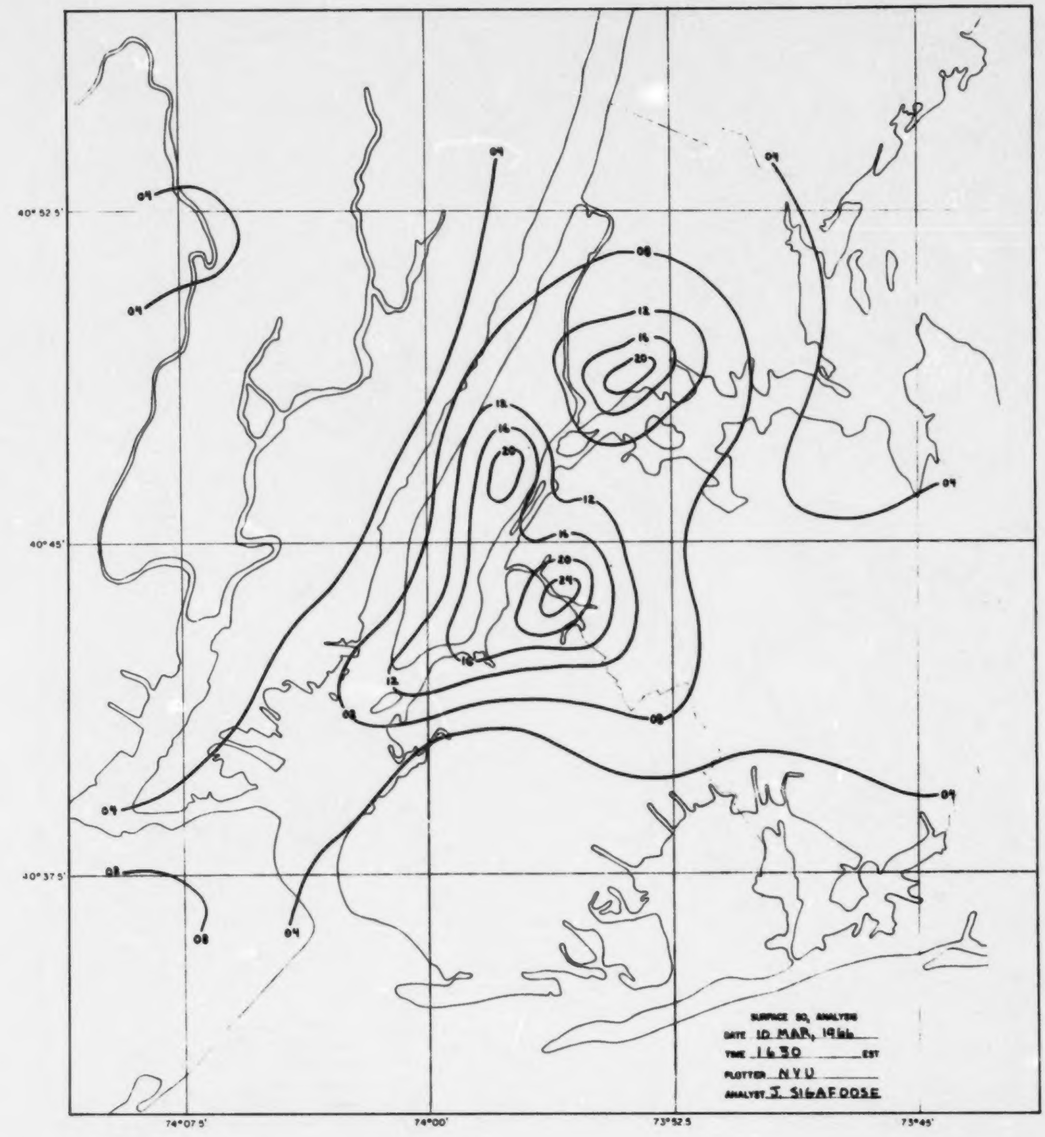
08
SURFACE SO2 ANALYSIS
DATE 6 DEC, 1966
TIME 1030 EST
PLOTTER NYU
ANALYST K. LEAP

Figure 19. Analyzed values of surface SO_2 concentrations in pphm for 1030 EST on December 6, 1966.


40°52.5'
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40°37.5'
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74°00'
73°52.5'
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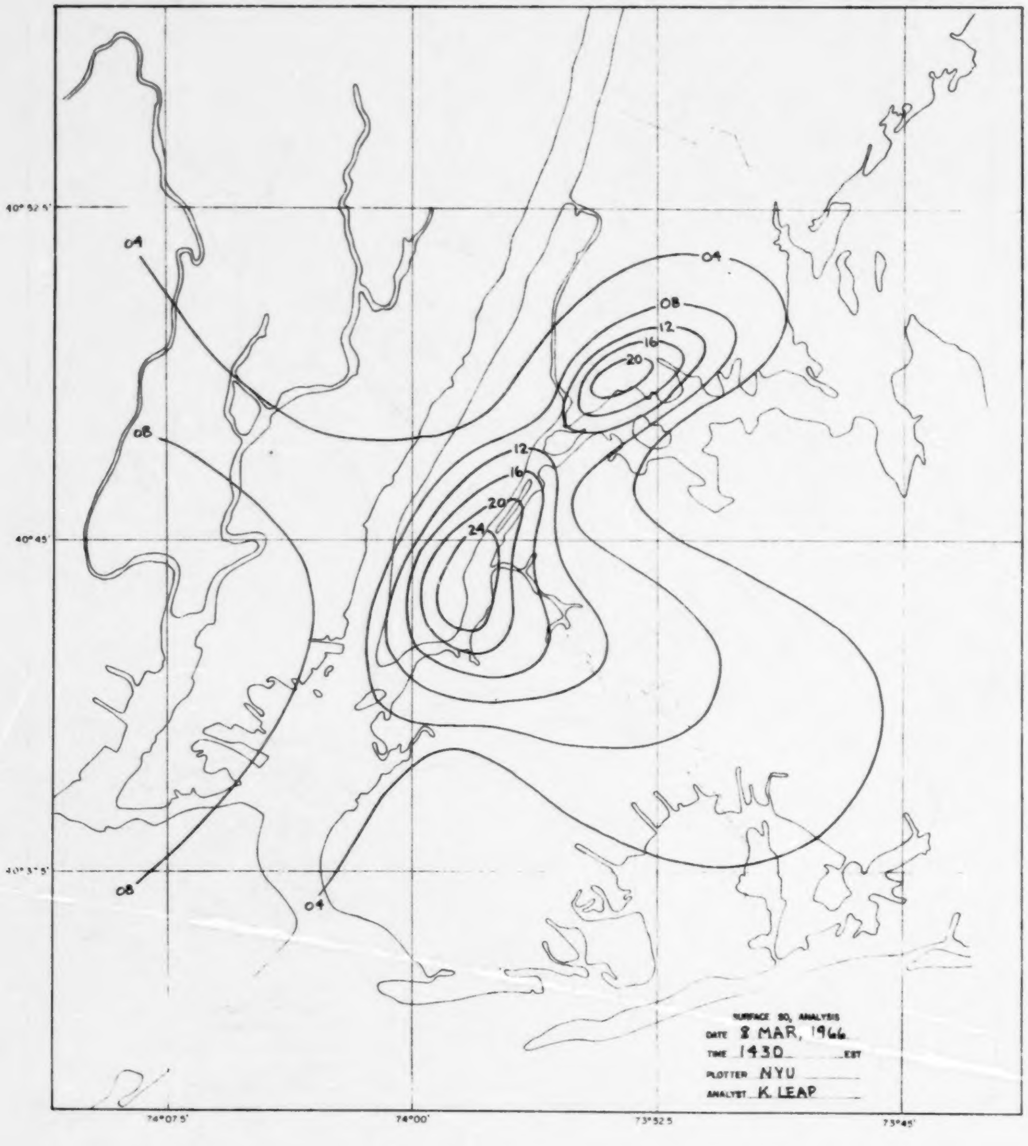
04
SURFACE SO₂ ANALYSIS
DATE 10 MAR, 1966
TIME 1630 EST
PLOTTER NYU
ANALYST J. SIGAFOOSE

Figure 20. Analyzed values of surface SO_2 concentrations in pphm for 1630 EST on March 10, 1966.


40°52.5'
40°45'
40°37.5'
74°07.5'
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73°52.5'
73°45'
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24
SURFACE SO2 ANALYSIS
DATE 8 MAR, 1966
TIME 1430 EST
PLOTTER NYU
ANALYST K. LEAP

Figure 21. Analyzed values of surface SO_2 concentrations in pphm for 1430 EST on March 8, 1966.

The isopleth interval used in the analyses was usually 8 pphm, but when the maximum concentration fell below 32 pphm, a 4-pphm interval was used. On occasion, intermediate isopleths were drawn if their inclusion would provide significant additional information.

When the isopleth analyses were constructed, the observations from the Group I stations were explicitly drawn for. Values from the Group II stations were looked at next (except during times when CO_2 corrections were not available), and then the Group III stations were examined to aid in determining the isopleth patterns. Finally, the data from the mobile observation sites were used to "fill in the gaps" and to provide more detail to the analyses.

The above "ranking" was carried out because: (1) the Group I Davises were calibrated by project personnel; (2) the Group II Davises were not calibrated by project personnel nor were they cross-calibrated against Group I Davises; (3) the Group III wet chemistry instruments were not calibrated by project personnel, nor were they cross-calibrated against readings from Davises; and (4) the mobile observations were not hourly averages, nor were they necessarily taken at the exact time for which the chart was constructed.

Additional input to the analyses was provided by the area and point source distributions discussed in Section 2. These distributions were used as aids in determining the location and horizontal extent of areas of maximum concentrations. The surface wind data discussed in Section 4 were also used in determining the directions in which the maximum concentrations would be advected, usually reflected in the configurations of the SO_2 isopleths.

DISCUSSION OF ANALYSES

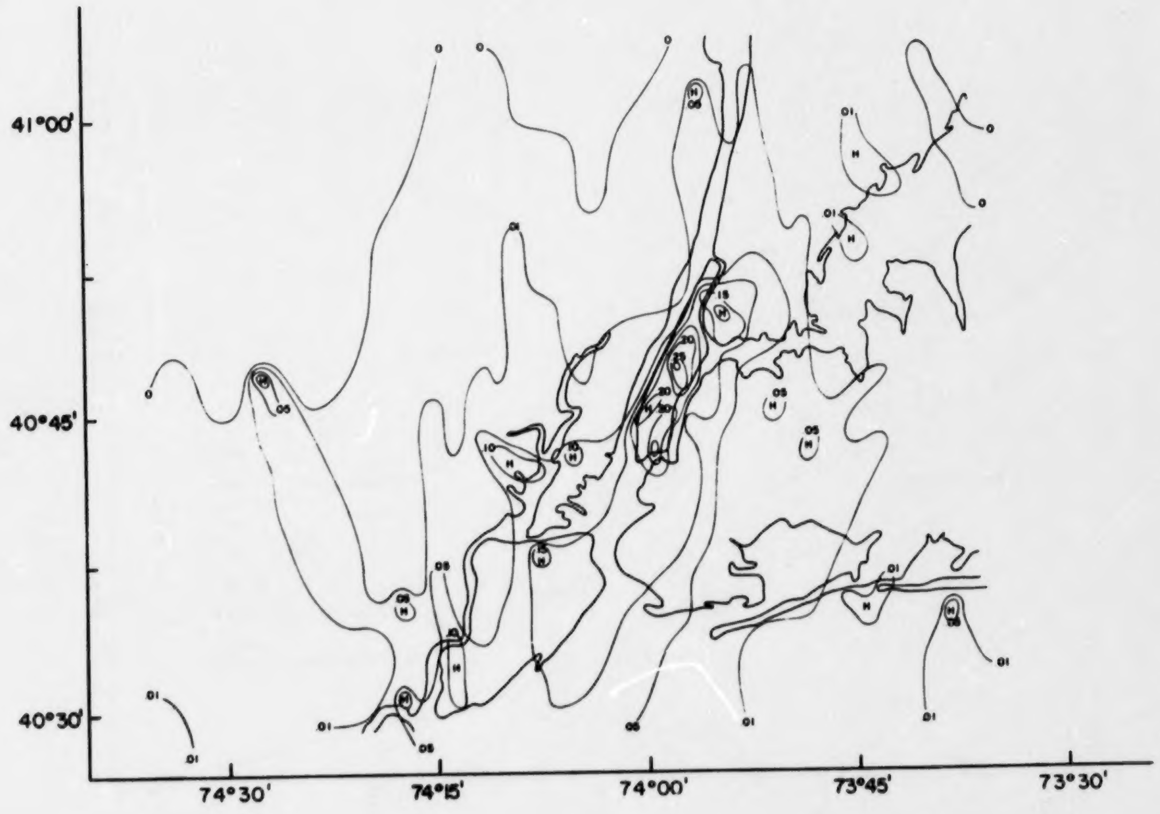
Analyses for the area of eastern New Jersey is somewhat dubious due to the sparsity of data in that region. In addition, isopleths were frequently curved in the vicinity of the large bodies of water in the study area in order to reflect the lower concentrations probably existing over these source-free regions. However, the effects of the smaller rivers and of Central Park rarely show up in the analyses, due to the absence of number of data points required to resolve details in the concentration field on the space scale of these geographic features.

Thus it is suggested that the present analyzed observed surface SO_2 concentration patterns be validated against simulated concentration patterns resulting from air pollution models using a horizontal area source grid spacing of about 2-3 km. Such a grid spacing was used in the Gaussian puff model of Shieh (1969), and in general his predicted SO_2 patterns in the area of Manhattan and The Bronx (Figure 22) compared quite well with the observed patterns for that area (Figure 21). When the grid spacing used in that model was reduced by a factor of five, finer detail resulted in the predicted SO_2 pattern (Figure 23), e.g., see the effect of the rivers around Manhattan, and of Central Park, in producing areas of reduced concentration.

A tabulation of the hourly averaged SO_2 values measured at all of the stations during the three "primary" test periods is given in Volume II. These values can be compared by applying quantitative statistical techniques to predicted concentrations obtained from an urban air pollution model, but care should be taken in using the Group II and Group III data for the reasons discussed above.

In addition, a series of SO_2 concentration profiles across Manhattan (along 79th Street) were constructed by Jurgrau (1969) using data obtained with the instrumented truck. He was interested in the effects of the source-free Central Park area on the buildup of SO_2 concentrations across Manhattan. The location of 79th Street is shown as the dashed line across Manhattan in Figure 23, while Central Park appears in the figure as the rectangular box in the middle of Manhattan. The actual sites where the truck stopped and made 5-minute SO_2 readings are given in Table 30. The western and eastern boundaries of the park are Central Park West and 5th Avenue, respectively.

As shown in Table 1, these traverses are only extant for one of the three re-analyzed test periods, i.e., the November 1966 period. However, the data were used by Shieh (1969) to compare predicted and observed concentration profiles across Manhattan (Figure 24). All of the traverses for the November 1966 period are included in Volume II.



41°00'
40°45'
40°30'
74°30'
74°15'
74°00'
73°45'
73°30'
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Figure 22. Predicted SO_2 concentration field for a 1-mile by 1-mile computational grid at 1200 EST on March 8, 1966 (from Shieh, 1969).

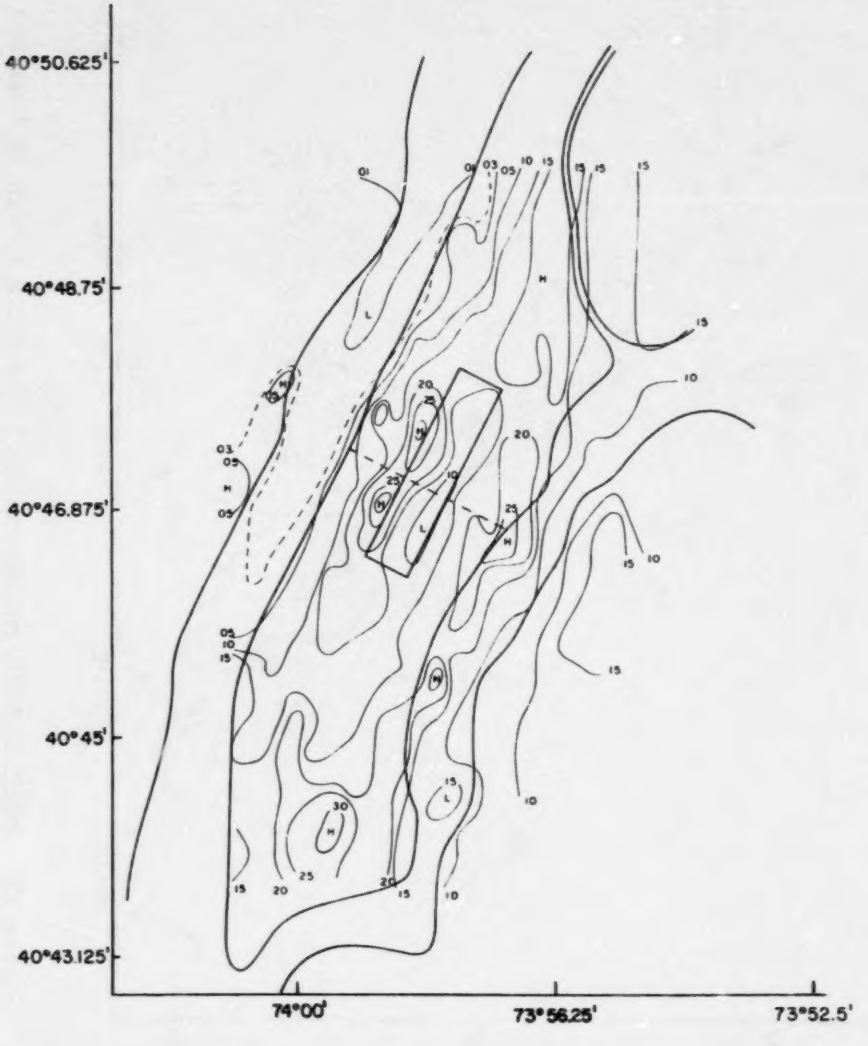
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Figure 23. Predicted SO_2 concentration field for a 0.2-mile by 0.2-mile computational grid at 1200 EST on March 8, 1966 (from Shieh, 1969).

TABLE 30. SITES APPEARING IN 79th STREET TRAVERSES

Site	Abbreviation
79th & East End	E.E.
79th & York	York
79th & First Ave.	1st
79th & Second Ave.	2nd
79th & Third Ave.	3rd
79th & Lexington	-
79th & Park	Park Ave.
79th & Madison	-
79th & Fifth Ave.	5th Ave.
79th & Central Park West	C.P.W.
79th & Columbus	Col. Ave.
81st & Amsterdam	Amst.
81st & Broadway	B'Way
81st & West End	W.E.
81st & Riverside	R.D.

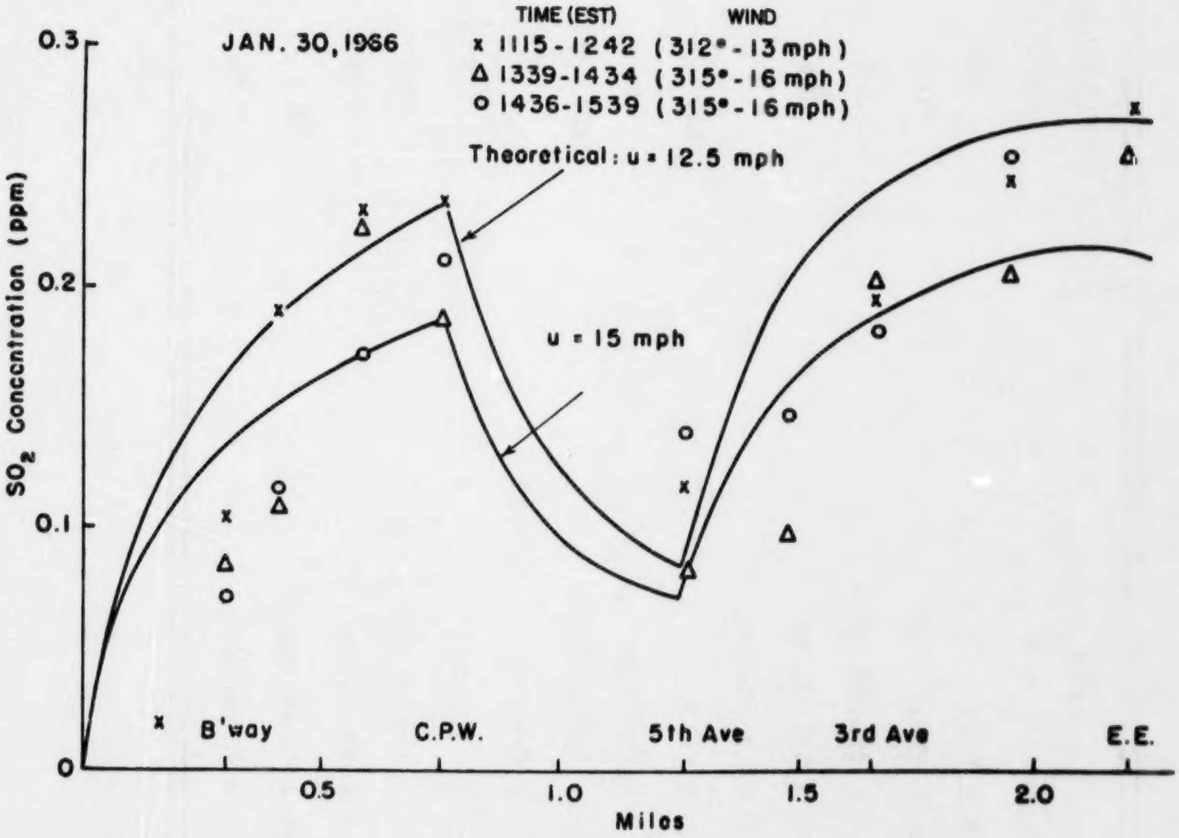

Figure 24. Predicted SO_2 concentrations (solid lines) versus observed data along a 79th Street crosstown traverse in the direction of the mean flow (from Shieh, 1969).

SECTION 7

SUMMARY

Volume I describes the data set collected during the New York City Air Pollution Project, conducted by New York University under the directon of the late Dr. Ben Davidson of the Department of Meteorology and Oceanography, New York University. Volume II includes tabulations of several of the more extensive components of the data set. Other parts of the data set are on file at the National Technical Information Service in Springfield, Virginia.

The data set includes mesoscale surface wind and SO_2 analyses, helicopter soundings of temperature and SO_2, emission inventories of SO_2, heat, and moisture from area and point sources, and pibal wind soundings. Data were collected during 12 observational periods carried out during the project, but complete data sets are presented in Volumes I and II for only three of the more interesting periods. In addition, Volume I includes a discussion of calibration and verification procedures.

The data collected during this Project have already proved useful in several air pollution and urban climate studies. It is hoped that others working in related fields will be able to make use of this unique data set.

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*Designates paper using NYU/NYC data set, and available at SJSU.

APPENDIX I

SUMMARY OF SYNOPTIC CONDITIONS DURING TEST PERIODS

TEST 1

Sept. 19, 1965: An anticyclone dominated the east coast south of NYC with a quasi-stationary front through the center of New York State (NYS) and Connecticut. The front moved (east to west) through NYC between 1800 and 2100Z, and the high associated with the new air mass was centered 400 miles east of NYC.

Sept. 20, 1965: The front that passed through NYC on the 19th washed out in central Pennsylvania by 1800Z, resulting in a large high forming over the entire east coast and western Atlantic.

Sept. 21, 1965: No change.

Sept. 22, 1965: No change on east coast, but after 0000Z, a cold front moved into the Ohio Valley.

Sept. 23, 1965: The front slowed in the Ohio Valley, but as the high on the east coast weakened, the front began to move eastward with many waves.

Sept. 24, 1965: The front entered eastern NYS by 0600Z, but remained quasi-stationary with waving. It passed NYC at 0300Z, moving from west to east.

TEST 2

Oct. 13, 1965: An anticyclone moved from West Virginia to Delaware, following a front located in the western Atlantic.

Oct. 14, 1965: The high moved northeast, but high pressure still dominated the entire east coast.

Oct. 15, 1965: A ridge still existed over the east coast, but by the end of the day a cold front moved into upper NYS.

Oct. 16, 1965: The front passed through NYC at about 0600Z, followed by a high from Ontario.

Oct. 17, 1965: The high first moved northeast, and then moved down the Hudson River to a position over NYC at 2100Z.

Oct. 18, 1965: The high remained stationary over NYC.

TEST 3

Cancelled

TEST 4

Dec. 7, 1965: A high was centered over the midwest, with ridging into the northeast. The high later moved southeast.

Dec. 8, 1965: The high moved into the southeast, still ridging into the northeast. By 1800Z, a front moved into upper NYS, and by 2100Z there was frontolysis, with a "peanut" low centered over Syracuse and Dover Air Force Base.

Dec. 9, 1965: The ridge was re-established by 0600Z, and the high became quasi-stationary over the southeast.

Dec. 10, 1965: A cold front entered upper NYS at 0900Z. It passed NYC at 1200Z, and by 1800Z the ridge formed a high centered in Ontario.

Dec. 11, 1965: The surface ridge line moved into northwestern New England, and there was a warm front through Washington, D. C.

Dec. 12, 1965: The Canadian high intensified, increasing the ridging over the east coast.

TEST 5

Feb. 2, 1966: A trough formed over the east coast between a low near Greenland and another low (with a frontal system) over Virginia.

Feb. 3, 1966: Weak ridging from Philadelphia to Oklahoma.

Feb. 4, 1966: A front entered upper NYS by 1500Z, with a wave centered over southeastern Ontario. Frontolysis occurred at 2100Z.

Feb. 5, 1966: A high centered over the Mississippi Valley dominated the entire eastern part of the country.

TEST 6

March 8, 1966: A long wave trough was over the northeast, with jets through the Ohio Valley and off the coast at Martha's Vineyard. At the surface, a dynamic high dominated the east.

March 9, 1966: The long wave trough weakened and the jet moved northward into NYS. The highest speeds moved into Maine and a short wave ridge moved into the southwestern part of the Ohio Valley. The surface high moved northeast across the Ohio Valley into NYS. By 1200Z it began to move south.

March 10, 1966: The long wave ridge aloft was building over the western Ohio Valley. The jet maximum was accompanying a short wave ridge and was losing strength. The surface high became stationary over Norfolk, Virginia and began changing its thermal structure. By 2100Z a cold front had just passed Watertown, New York (moving south) and the high was breaking down.

March 11, 1966: A second jet maximum was over Quebec in association with a well-developed short wave trough and a closed low at 500 mb over Montreal.

The front moved through NYC at 1200Z. Following the front there was ridging from a dynamic high over Quebec. The ridge was bridging the front in the NYC area during the afternoon.

March 12, 1966: The upper level system moved eastward across the maritime provinces and a weak short wave ridge developed in association with the convergence zone of the jet maximum. The long wave pattern remained unchanged. By 0300Z the surface front moved southward to Washington, D.C., and the high moved south-southeast with its center remaining in Quebec.

TEST 7

May 3, 1966: A high was centered over the Missouri Valley with ridging into the northeast. There was frontogenesis over Maine, and a cold front moved rapidly into NYC.

May 4, 1966: The front moved into the NYC area by 0000Z and a post frontal high in Maine moved southeast through the Washington, D.C. area.

May 5, 1966: The high moved off the coast, and a second front was over Maine.

May 6, 1966: The front moved through NYC between 0600 and 1200Z. At 1200Z, a short wave formed over Cleveland a wave moved through NYC after 1800Z.

May 7, 1966: A post frontal trough remained over the northeast.

TEST 8

Oct. 4, 1966: A stationary high existed in the Atlantic off of NYC and a cold front moved through the Ohio Valley into NYS by 0100Z.

Oct. 5, 1966: The front passed NYC between 0600 and 1200Z, and the "triple point" also went through. A post frontal high was centered over the Missouri Valley.

Oct. 6, 1966: The high moved northeastward into the Ohio Valley.

TEST 9

Nov. 1, 1966: A front with waves moved through the middle of NYC and then remained stationary.

Nov. 2, 1966: A major wave developed over Georgia and moved northward along the front into Pennsylvania.

TEST 10

Nov. 15, 1966: At 0000Z, the jet was through the Ohio Valley and off of the coast at Cape Hatteras. The axis of the long wave trough was through an area northeast and east of NYC. By 1200Z, the jet moved to a position north of the city, and there was a jet maximum over northwest Ontario. At the surface at 0600Z, a dynamic high was centered in northwest Ontario, with ridging into the Ohio Valley.

Nov. 16, 1966: The flow was becoming more zonal, with the jet split into two cores. The primary core was over southern Quebec, while the secondary core was over the southern Ohio Valley. At 0000Z, the surface ridge was in NYS, while six hours later the high was centered over Alabama. By 1800Z, the flow at NYC was southwest, with a warm front near Buffalo.

Nov. 17, 1966: The two jet cores merged and came off of the east coast at Washington, D.C. A strong maximum was developed over Wisconsin. At 0000Z, the surface front extended from Watertown, NYS to Providence, RI. It then moved northward and became quasi-stationary in northern New England, with southwesterly flow remaining over NYC.

TEST 11

Nov. 23, 1966: A high centered over Washington, D.C. dominated the entire east coast.

Nov. 24, 1966: The high moved southward into Georgia.

Nov. 25, 1966: Weakening of the ridge in the northeast allowed some quasi-stationary frontal activity in the northwestern part of New England.

TEST 12

Dec. 6, 1966: At 0000Z, a dynamic high at 850 mb over Charlestown, S.C. dominated the entire east coast. It was beginning to change its structure to a warm core high. The surface pattern was generally the same as that at 850 mb.

Dec. 7, 1966: The high at 850 mb was a stationary warm core high centered at 30N and 75W. The surface pattern was generally the same as that at 850 mb.

Dec. 8, 1966: By 0000Z a front at 850 mb was pushing into the Ohio Valley, increasing the wind speed over NYC up to 30 kts. (from the west). By 0600Z, the surface high was off of the coast, and there was strong southwesterly flow through the entire east coast.

APPENDIX II

SUMMARY OF INVERSION DATA FROM SOUNDING TAKEN AT THE NATIONAL WEATHER SERVICE SITE AT J.F.K. AIRPORT

Data includes elevation of inversion base z_B, elevation of inversion top z_T, temperature increase through inversion ΔT, and thickness of inversion Δz.

APPENDIX II

Date	Time (EST)	z_B(m)	z_T(m)	ΔT(C)	Δz(m)
10/16/64	0615	0	510	7.7	510
10/28/64	0615	0	440	9.1	440
10/29/64	0615	0	610	0.8	610
03/02/65	0615	0	310	1.3	310
03/03/65	0615	0	300	1.6	300
10/14/65	0615	0	290	1.1	290
10/15/65	0615	0	380	2.5	380
02/02/66	1215	380	490	1.4	110
03/09/66	0615	0	310	0.7	310
03/10/66	0015	230	330	1.7	100
	0615	0	230	3.9	230
03/11/66	0015	0	360	3.7	360
	0615	0	200	3.9	200
05/03/66	0015	360	480	0.8	120
	0615	2100	2450	2.9	350
	1215	1920	2070	1.2	150
	1815	158	480	3.9	322
05/04/66	0015	2390	2500	0.0	110
	0615	1840	1970	1.1	130
	1215	2210	2330	1.5	120
	1815	4170	4490	0.8	320
05/05/66	0015	1480	1810	0.2	330
	0615	2200	2690	0.2	440
	1215	200	310	0.4	110
	1815	146	1510	0.6	1364
05/06/66	0015	0	1020	5.9	1020
	0615	0	150	1.9	150
	1215	3470	3700	1.1	230
	1815	1120	1600	2.0	480
03/23/66	0015	280	530	8.9	250
	0615	340	830	6.8	490
05/07/66	0015	1350	1650	0.2	300
	0615	1150	1980	2.8	830
	1215	1520	1680	2.6	160
	1815	260	410	2.1	150
05/08/66	0015	440	880	3.4	440
05/25/66	0015	180	310	1.8	130
	0615	0	540	0.3	540
06/09/66	0015	0	320	2.5	320
	0615	0	320	2.5	320

(continued)

APPENDIX II (continued)

Date	Time (EST)	z_B(m)	z_T(m)	ΔT(C)	Δz(m)
06/16/66	0015	0	220	1.0	220
	0615	0	90	4.0	90
	1215	110	250	5.8	140
06/22/66	0615	380	650	2.4	270
07/20/66	0615	480	550	2.0	70
07/21/66	0615	170	320	0.9	150
09/08/66	0615	490	610	0.8	120
10/04/66	0015	920	1120	0.7	200
	0615	1700	1920	3.9	220
	1215	210	330	0.0	120
	1815	190	320	1.6	130
10/05/66	0015	2280	2470	0.3	190
	0615	1210	1270	2.3	60
	1215	2080	2390	0.2	310
10/06/66	0015		NONE		
	0615	1530	1680	3.1	150
	1215	1426	1730	2.7	310
	1815	1300	3730	3.6	2430
10/07/66	0015	750	900	0.6	150
10/26/66	0015	0	90	3.8	90
	0615	0	350	3.2	350
10/27/66	0015	0	280	1.2	280
	0615	0	290	2.0	290
11/01/66	0015	1290	1540	1.1	250
	0615	0	380	.5	380
	1215	1070	1270	1.1	200
	1815	1170	1400	0.6	230
11/02/67	0015	0	280	2.2	280
11/15/66	0015	1970	2160	.4	190
	0615	1410	2300	5.4	890
	1215		NONE		
	1815	1490	2480	1.8	990
11/16/66	0015	300	670	0	370
	0615	810	1290	3.5	480
	1215	1040	1560	4.0	520
	1815	1160	1500	3.6	340
11/17/66	0015	730	1040	0.4	310
	0615	280	640	3.0	360
	1215	340	490	1.8	150
	1815	0	206	3.2	206
11/18/66	0015	0	620	1.0	620
11/23/66	0015	0	1000	0.7	1000
	0615	0	950	8.3	950
	1215	430	600	2.3	170
	1815	0	221	1.8	221

(continued)

APPENDIX II (continued)

Date	Time (EST)	z_B(m)	z_T(m)	ΔT(C)	Δz(m)
11/24/66	0015	0	550	7.3	550
	0615	0	320	12.4	320
	1215	470	700	2.5	230
	1815	0	185	5.0	185
11/25/66	0015	0	110	7.1	110
	0615	0	440	6.3	440
	1215	1090	1530	0	440
	1815	0	200	3.8	200
11/26/66	0015	0	160	2.3	160
12/06/66	0015	1220	1950	1.4	730
	0615	450	1060	3.6	610
	1215	1150	1280	7.5	130
	1815	790	1190	6.4	400
12/07/66	0015	0	1522	1.8	1522
	0615	870	1300	4.2	430
	1215	740	1440	3.7	700
	1815	480	1360	2.3	880
12/08/66	0015	0	1470	1.1	1470
	0615	0	710	8.1	710
	1215	0	570	1.8	570
	1815	0	230	4.9	230
12/09/66	0015	0	139	6.7	139